FIRST SEMIANNUAL REPORT

for

TIME CODE STUDY

(15 Sept 1964 - 28 May 1965)
Contract No.: NAS5-9739

Prepared by

Electronic Engineering Co. of California
1601 East Chestnut Ave.
Santa Ana, California

for

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

4

~~FIRST~~ SEMIANNUAL REPORT 2

for

3 TIME CODE STUDY 4

7 (15 Sept 1964 - 28 May 1965) 9 10CV

Contract No.: NAS5-9739

25 29 11CV

Prepared by

1 Electronic Engineering Co. of California
1601 East Chestnut Ave.
9 Santa Ana, California 3

for

29B. SAR-1 END

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

TIME CODE STUDY

Summary

The Time Code Study presents a survey and analysis of the techniques used in time code generation, recording, decoding, transmission and distribution with particular attention to the time code formats used. An analysis of time code characteristics is presented in terms of the time code formats which are in general use.

CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF TABLES (continued)

I. INTRODUCTION

A. General

The objective of the Time Code Study is to survey and analyze the various techniques used in providing synchronous time information to be used in "time tagging" recorded data, with particular attention to be given to the time codes used and the compatibility of these time codes.

The study is to include the following seven specific tasks as stated in the contract work statement.

Task I	-	Study time code generation, recording and decoding techniques.
Task II	-	Study time code comparison and error detection techniques to increase accuracy and reliability
Task III	-	Study time code transmission techniques from satellite to ground and from station to station.
Task IV	-	Study time code distribution techniques.
Task V	-	Recommend improvements in existing time code systems, including time code conversion equipment.
Task VI	-	Prove or demonstrate the feasibility of the improvements recommended in Task V.
Task VII	-	Recommend a new time code system using a minimum number of time codes.

B. Organization of the Study

The study, as set forth in the seven tasks, is divided into several sections.

Section 1 contains material resulting from the performance of the first four tasks. These four tasks cover all of the various areas of timing with which the study is concerned. A survey and analysis of each of the subtopics within each of the tasks is presented to provide general background material as well as some detailed analysis within each of the subject areas.

Section 2 contains detailed analyses of specific system aspects of timing which involve several of the separate areas of timing covered in Section 1. Specific analyses planned at this writing are:

a. Analysis of Time Code Formats

b. Analysis of Timing Accuracy

c. Analysis of Timing Reliability

d. Analysis of Timing Distribution

Section 3 contains the work involved in performing Tasks V and VI; recommending improvements to existing systems based on the results of previous sections of the study and the justification of those recommendations.

Section 4 contains the work involved in the performance of Task VII, recommending a new time code system if the previous sections of the study indicate that such recommendations are in order.

C. Scope and Purpose of This Report

This report presents material which indicates the present status of the study. Material is presented on section 1 and section 2, described above. Material on section 3 and section 4 will be presented in later reports.

Section 1 of this report provides coverage of all areas of timing except (a) Code Comparison and Error Detection Techniques (Task II), and (b) Time Code Transmission from Satellite to Ground (part of Task III), with greatest emphasis on the material of Task I.

Section 2 of this report provides the analyses of (a) Time Code Formats and (b) Timing Accuracy.

Greatest emphasis is placed on the time code analysis. This analysis provides a tabulation of 33 existing time codes and a format drawing of each. An analysis of these existing time code formats is provided as well as general analysis of time code characteristics.

The analysis of timing accuracy is concerned with the accuracy of timing signals as recorded with the data. The analysis is primarily concerned with the time delays encountered in time code generation, transmission, distribution, decoding, and recording processes and the constancy of these delays. The analysis does not include timing inaccuracies introduced by generator synchronization and frequency standard inaccuracies.

II. SECTION 1. SURVEY AND ANALYSIS OF GENERAL TIMING TOPICS

A. TASK I

1. Time Code Generation Techniques

General

The basic technique for generating time signals which has been used almost universally for the past fifteen years is counting the individual cycles of a more or less stable electronic oscillator in an electronic counter. Prior to the general use of electronic oscillators and counters, time signals for instrumentation purposes were generated by sets of switches operating from a cam-shaft driven by a synchronous motor.

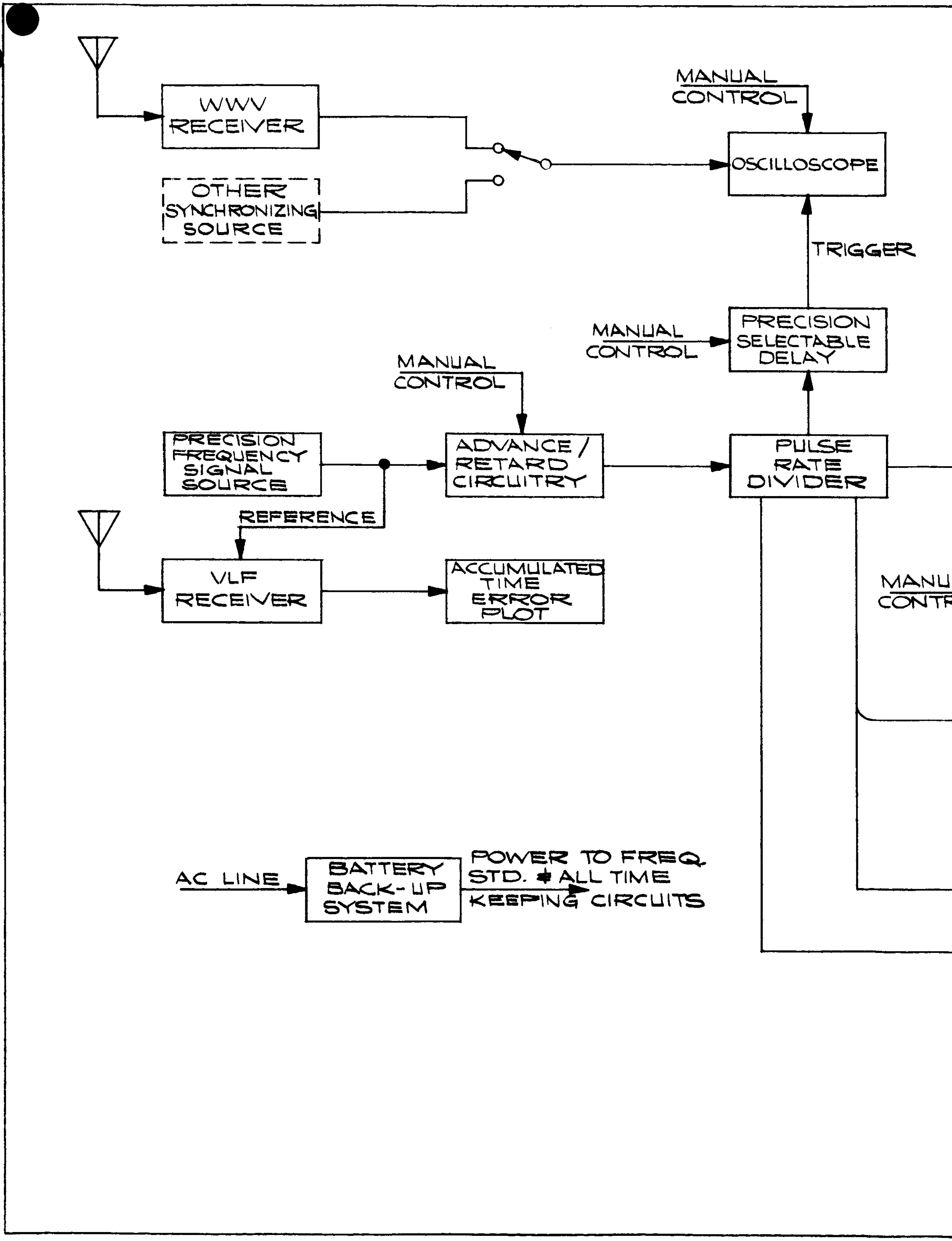
Although the stability and precision of the oscillators used as standards has increased several orders of magnitude, the speed and reliability of the electronic counting circuitry has increased and better techniques for establishing and maintaining generator synchronism have been developed during the past ten or fifteen years; the basic technique for generating time signals is the same. Electronic (or atomic) oscillators can be provided with accuracies and stabilities much better than required to provide time signals. Electronic counting circuitry can be provided with sufficient speed and reliability to count the cycles of these frequency standards. There does not seem to be, at present, a superior technique for generating time signals.

Figure 1 is a generalized block diagram of the typical Time Code Generation System. Individual generators will vary from this basic drawing in some areas, but the fundamental features are illustrated.

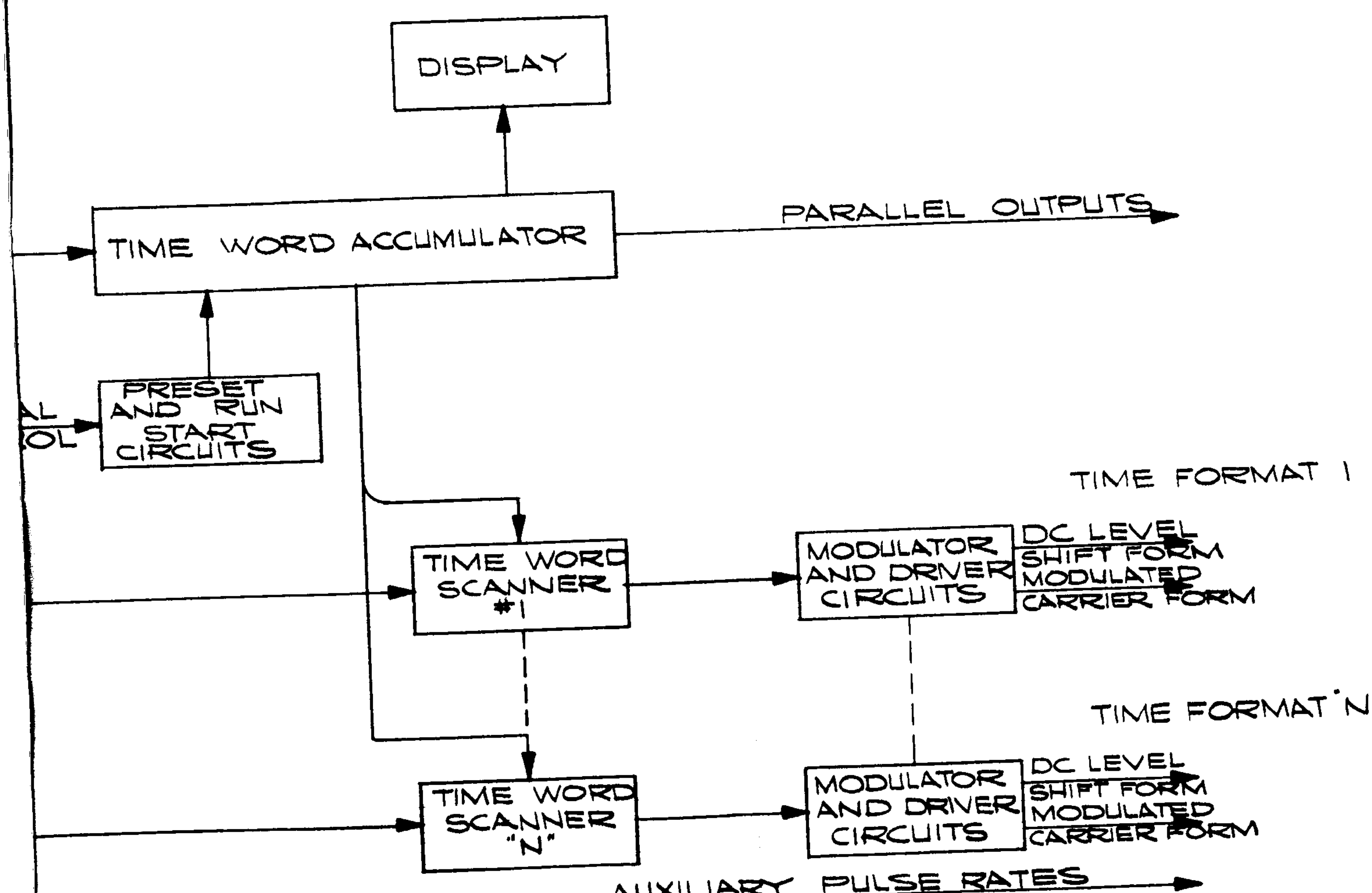
The fundamental purpose of the study is to analyze techniques used in timing rather than the design of the hardware used to implement those techniques. However, it will be necessary to refer to generalized block diagrams such as figure 1 to analyze certain techniques. For example, techniques for synchronizing any time generator require means of advancing or retarding the phase of the basic timing signal. Techniques for accomplishing the advance-retard operation involve such considerations as desired rates and resolution. To discuss these techniques some reference must be made to typical hardware.

Precision Frequency Signal Sources

The study of the type of frequency standards to be used to drive timing systems is not a part of this study. The frequency standard will only be considered as it influences other characteristics of a timing system. As the need for more precise time synchronization increases, more stable frequency standards are required. As the stability of the frequency standard increases, the time generator should provide greater resolution in synchronization.



MANUAL CONTROL
WWV RECEIVER
OSCILLOSCOPE
OTHER SYNCHRONIZING SOURCE
TRIGGER
MANUAL CONTROL
PRECISION SELECTABLE DELAY
MANUAL CONTROL
PRECISION FREQUENCY SIGNAL SOURCE
ADVANCE / RETARD CIRCUITRY
PULSE RATE DIVIDER
REFERENCE
VLF RECEIVER
ACCUMULATED TIME ERROR PLOT
AC LINE
BATTERY BACK-UP SYSTEM
POWER TO FREQ. STD. & ALL TIME KEEPING CIRCUITS



TYPICAL TIME CODE GENERATION SYSTEM

ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA
SANTA ANA

DWG NO. FIG. 1

We will assume that all time generating systems considered will be compatible with either good crystal oscillators with stabilities in the order of 1 part in 10^{10} per day or with atomic standards.

Time Generator Synchronization

While techniques for time generator synchronization are not a part of this study, features of the generator involved in the synchronization process must be considered. As mentioned above, the degree of synchronization obtainable affects the required resolution of the advance-retard circuitry and the resolution of the calibrated precision delay used in the synchronization process. The ease with which synchronization can be obtained affects such things as the degree of battery backup required for a timing system. For example, a very few years ago the best source of generator synchronization was the standard time signal from radio station WWV. Synchronization to within ±1/2 millisecond could be obtained after careful plotting of the time difference between the generator time signal and the received WWV time tick for a period of several months. With such a technique in use, it was highly desirable that the generator circuitry be backed up with batterypower -- at least down to the basic 1 pps time signal -- to avoid loss of synchronization and the waste of several months' work in the event of a line power failure. If precise synchronization was readily available from some other source, such as Loran C signals, only the frequency standard itself need be backed up to maintain the precise signal source. The generator could be restarted and accurately resynchronized in a short time following the return of line power.

Synchronization techniques and frequency standard stability affect time code generator design other ways. For example, with present day synchronization techniques and the use of relatively stable crystal oscillators (1 part in 10^{10} per day) as basic signal sources, the problem of establishing generator synchronization and maintaining synchronization once established have been two separate problems and have involved two separate subsystems within the timing system. Up to the present time, synchronization of a time code generator has been established by comparing the basic generator signal (usually the 1 pps) with some reference signal by means of an oscilloscope and an adjustable precision delay in the manner indicated in figure 1. As mentioned above, the WWV time tick has been the primary reference for obtaining synchronization. The precision delay is set to delay the time generator 1 pps signal an amount equal to known time delays in reference; the average propagation time in the case of WWV. The delayed generator signal is used to trigger an oscilloscope on which is displayed the reference signal. The generator advance-retard control is operated until the reference signal is displayed at the proper time on the oscilloscope. Other reference signals can be used to establish synchronization of the generator such as Loran C or a traveling clock.

Generator synchronization, once established, must be maintained. The method which has had widespread acceptance up to the present time has been that of comparing the generator frequency standard to VLF radio transmissions. This is accomplished by means of a VLF tracking receiver which produces a plot on a strip chart recorder of the accumulated time drift of the clock operating from the generator frequency standard. The clock can be reset periodically by means of the advance-retard controls to maintain synchronization of the basic generator signal.

Obviously, the more stable the frequency standard, the less often the clock must be reset. With an atomic standard, only occasional resetting would be required and the plot to a VLF transmission would be for an operational check only.

The Electronic Engineering Company has found in our work with timing over the years that best results are obtained by designing time generators which are functionally simple and straightforward in operation to be manually operated by qualified operators. We have found such systems are superior to complex systems which provide automatic synchronization and automatic error correction. The system depicted in figure 1 is typical of this basic system.

In such a system, synchronization can be established, as described above, to any reference which might be available.

Correction of accumulated time error caused by drift of the frequency standard can be made manually after continual comparison by the operator to several VLF transmissions or to a local atomic standard.

The system should be designed in such a way that it can either operate with extremely stable frequency standards holding synchronization within a few microseconds or can operate with less stable oscillators in timing systems where extreme stabilities and such a high degree of synchronization is not required. The resolution of the advance-retard circuitry and the adjustable precision delay in such a system should be at least 1 μsec to be compatible with present day oscillator stabilities and synchronization requirements.

As mentioned above, at the present time the problems of achieving generator synchronization and maintaining synchronization once achieved involve two separate subsystems in a time generator. The use of Loran C signals produces a practical means of achieving synchronization and maintaining synchronization from a single source. Technical personnel at the Air Force Eastern Test Range are planning to use a Loran C tracking receiver to provide both frequency and phase correction in the new timing system scheduled for delivery within the next few months.

At the present time, Loran C signals can provide synchronization to at least 50 μsec in the United States (50 μsec on skywave signals, better than 10 μsec on ground wave signals). Tracking receivers are available which can provide a phase track of the stabilized 100 kc carrier and, thus, also provide means of accumulating time errors caused by oscillator drift -- all from one source. At the present time, the limitations of such a system are (1) the limited coverage of the Loran C system and (2) the complexity and cost of a tracking Loran-C receiver.

Generator Advance-Retard Circuits

The typical advance-retard circuit in a time generator provides means of advancing or retarding the phase (time) of all signals in the generator, following the advance-retard circuits at either "fine" or "coarse" rates. The "coarse" rate is used for initial synchronization where the generator 1 pps signal can be a large fraction of a second out of phase with the reference. The "fine" rate is used to achieve a chosen degree of synchronization and to correct subsequent time errors caused by oscillator drift.

A system which has been found to satisfy the requirements for good resolution in making fine corrections and a reasonable operating speed when accomplishing initial synchronization is to provide a digital advance-retard circuit, operating at coarse and fine rates (10 milliseconds per second and 500 microseconds per second) and a continuously variable phase shifter operating at the 10 kc level in the divider chain (providing a resolution of 100 μsec per revolution).

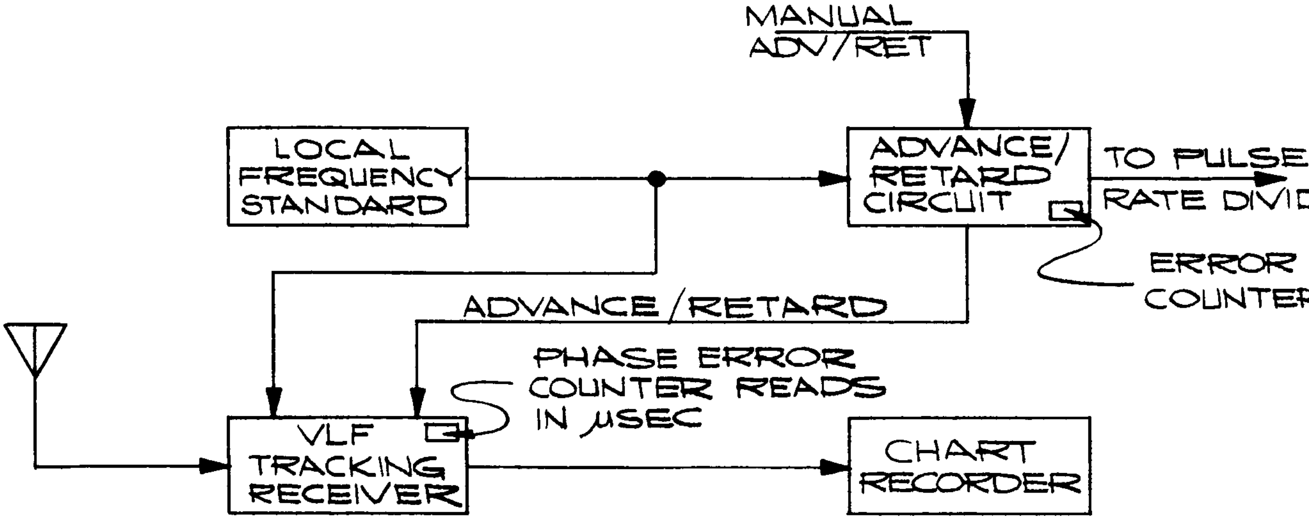
The advance-retard action is operator controlled by a pushbutton and continues at the rate selected as long as the button is depressed. When operating at the fine rate, a pulse shift of 100 μsec is introduced for each of the 5 pps pulses gated through. At this rate, the operator can operate the pushbutton in such a way that only one pulse is gated through and the generator signal can be set to within ± 50 μsec of the reference signal.

The continuously variable phase shifter can then be used to synchronize the generator signal to the reference signal with 1 μsec resolution. A resolver with a calibrated dial, operating at the 10 kc level, is used to implement the continuously variable phase shifter.

Some timing system users desire that a permanent record of both time drift errors and subsequent clock error corrections be maintained for analysis at any time. This can be accomplished by displaying the clock corrections (either advances or retardations) on the chart recorder plot generated by a VLF receiver. (The plot of accumulated time error of the local clock with respect to a stabilized VLF transmission.) This is accomplished as shown in figure 2.

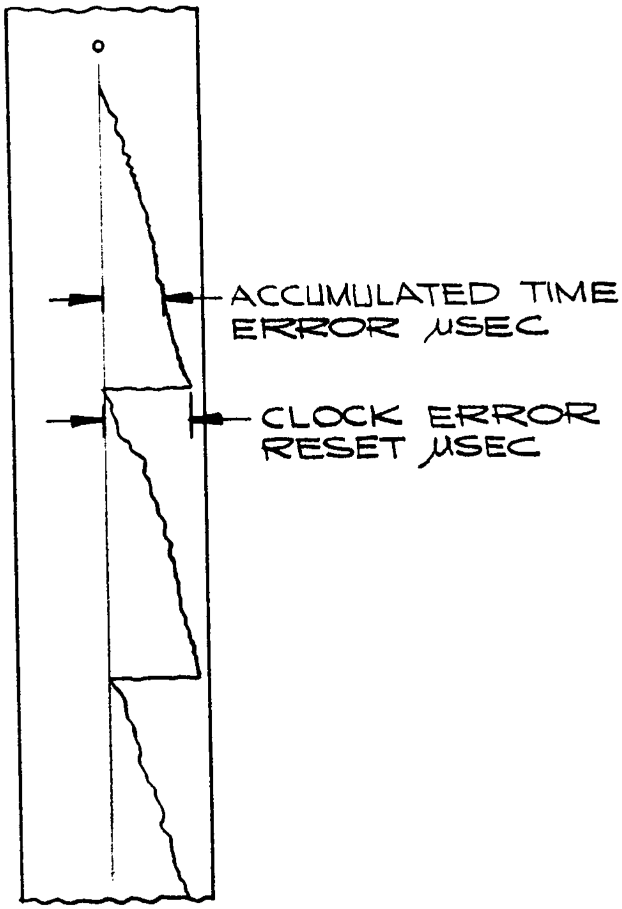
Dividers Used in Implementing Time Generators

Flip-flop dividers and counters have been used almost universally for several years in implementing time generators. While


MANUAL
ADV/RET
LOCAL
FREQUENCY
STANDARD
ADVANCE/
RETARD
CIRCUIT
TO PULSE
RATE DIVI
ERROR
COUNTER
ADVANCE/RETARD
PHASE ERROR
COUNTER READS
IN μSEC
VLF
TRACKING
RECEIVER
CHART
RECORDER

DER

RESET
R μSEC



TYPICAL
CHART RECORDING

CLOCK ERROR
PLOTTING SYSTEM

ELECTRONIC ENGINEERING COMPANY
OF CALIFORNIA
SANTA ANA

DWG NO
FIG. 2

regenerative dividers are useful in the higher frequency stages, it is our opinion that flip-flop dividers are superior below the 100 kc level for several reasons.

a. Operation is independent of frequency, one basic flip-flop decade can be used at all rates in a generator, all the way from 100 kc to 1 pulse per day.

b. Propagation down a divider string and accumulator is constant for each stage and can be made small by using high speed logic or can be eliminated by using gated logic.

c. Flip-flop circuits using transistors have been developed to the point where they are extremely reliable and can operate reliably in the presence of considerable electrical noise.

d. The use of flip-flops in generating precision width code signals produces signals which have precision trailing edges as well as precision leading edges.

We will consider that all generators discussed will be implemented with flip-flop dividers and counters.

Certain types of regenerative dividers have a property that can either be an advantage or a disadvantage, depending on where they are used. In such dividers, if a cycle is "missed" the divider will stop while a flip-flop divider will continue operating but will be out of phase by one period of the cycle dropped. In cases where synchronization is of the utmost importance, the divider that stopped would inform the operator of the failure and the system could be restarted and resynchronized. In some applications, it would be desirable for the generator to continue operating even though it was out of synchronism.

Degree of Coherency Between Generator Outputs

As the degree of time generator synchronization required approaches one microsecond, the coherency of the various generator timing outputs becomes more important. For example, a data acquisition system might be sampled by a precision 10 pps signal from the time generator. This 10 pps signal should be coherent with the basic generator 1 pps "on time" signals. It is felt that all generator output signals which might be used for precision timing purposes should be coherent with the generator "on time" output within 1 μsec.

Time generators implemented with asynchronous or non-gated flip-flops must use flip-flops which are fast enough to keep the propagation delay (or carry delay) to a minimum. Typical delays for generators implemented with 1 mc circuits is 100 nanoseconds per flip-flop.

The total propagation delay from the input to the pulse rate divider section to the last stage of the accumulator section is dependent on the type of coding used as well as the speed of the individual flip-flop. For example, a system using pure binary dividers and counters will generate one increment of delay for each flip-flop in the string. A counter using 1-2-4-8 coded decades will provide a propagation delay of only two increments per decade (or four flip-flops) since only two flip-flops change state when the count of ten is reached.

The 1 pps signal in a generator is usually used as the reference or the "on time" signal. In generators using asynchronous dividers and counters, all rates faster than the 1 pps pulse appear early with reference to the 1 pps signal and all rates slower than the 1 pps signal appear later than the 1 pps signal.

Propagation or carry delays can be eliminated in the outputs of time code generators by gating all output signals with a common signal. When using this technique, standard asynchronous flip-flops are used in implementing the pulse rate divider and accumulator sections but all output signals are gated and are therefore coherent. The only non-coherency will be the difference in delays through separate logic circuits of the same type. These differences are typically less than 100 nanoseconds.

All propagation and carry delays can be eliminated in a time code generator by using synchronous logic throughout. The disadvantages of implementing such a generator are additional complexity and cost of synchronous logic.

Accumulator Time Setting Capability

The accumulator of a time code generator must, of course, have the capability of being set to the proper time. The typical time generator contains a RUN-SET control which disconnects the basic generator signal (usually 1 pps) at the output of the Pulse Rate Divider from the Accumulator -- thus stopping the accumulator. When in the SET position, additional SET controls are provided which gate a slow pulse rate (such as 1 pps) into each section of the accumulator, thus providing means of advancing each section of the accumulator to a selected starting time.

It is desirable to keep the time required to preset the accumulator to within a few minutes, therefore, the number of stages in each group which is preset by a single control should be as small as practical. For example, in an accumulator coded in BCD hours, minutes, and seconds, one set button might be provided for hours, one for tens of minutes, one for units of minutes, one for tens of seconds, and one for units of seconds. If 1 pps was gated into each section to advance the counter, it could take 24 seconds to set hours, 6 seconds for each of the tens minutes and seconds decades, and 10 seconds for each remaining decade.

After the accumulator has been preset and the generator 1 pps signal synchronized to the reference, the clock is started at the time to which the accumulator has been preset by manually throwing the RUN-SET switch to RUN. This switch can be operated at any time between the 1 second pulse, occurring at the preset time, and the next 1 second pulse.

The Electronic Engineering Company has found that the system described above for setting and starting a time generator is satisfactory. In our opinion, it is more desirable than automatic systems. While automatic systems relieve the operator of any responsibility in the process, they reduce the flexibility of the system.

Operator Error Protection

The fundamental idea is to prevent the loss of timing by operator error or human accident. The most satisfactory procedure is to recess all controls which might cause the loss or change of timing behind doors on the front of the control panel and to make as many controls as possible inoperative when the generator is in the "Run" mode. It is preferable to recess (1) frequency setting controls on the frequency standard, (2) advance-retard controls, (3) the RUN-SET switch, and (4) accumulator presetting controls.

Another method of achieving protection from operator error is to provide a key operated switch which makes all of the above mentioned controls inoperative except when the key is inserted and turned.

2. Recording of Time Codes

General

Time is a specialized form of data whose value is a steady progression. In order to provide high resolution data in an easily distributable form, time data to be recorded is usually generated and distributed as coded, electrical signals.

Time is recorded to allow velocity and acceleration computation, and to provide correlation of several data sources covering one experiment.

Time is usually recorded as an auxiliary piece of data on a recorder whose primary specifications were chosen on the basis of the data recording requirements. The data to be recorded will have some upper limit on its frequency of valid interest. The recording media (paper, magnetic tape, etc.), will have to move by a resolvable increment in the half period of the highest data frequency. The minimum time interval resolvable (presuming the proper choice of time code format) will be of the same magnitude as the aforementioned half period of the highest resolvable data frequency. If the time code format chosen does not have identifiable time increments of adequate resolution, the accelerate/decelerate capabilities of the record media transport mechanism may be such that no significant change in volocity can take place in the interval between identifiable portions of the time code and, therefore, the distance between identifiable time points can safely be interpolated accurately.

Magnetic Tape Recording Methods

a. Direct Recording

In this method, a current proportional to the amplitude of the time code signal is passed through the record head. This produces a pattern of varying flux density that is a replica of the time code signal.

The time codes recorded using the Direct Record method are usually of the amplitude modulated carrier wave type. The carrier frequency is usually an integral power of ten (100, 1000, etc.) and is usually ten times the basic bit rate of the time code. As an example, the modulated carrier IRIG B code has a basic bit rate of 100-bits per second and uses a 1 kc carrier frequency. These amplitude-modulated carrier codes are necessary because the magnetic tape reading process yields an output voltage that is proportional to the rate of change of flux density. Consequently, if the pulse width coded dc level shift codes were recorded, the playback process would yield output voltages at the flux transitions representing the leading and trailing edges of the code pulses, but the envelope of the time code signal would be lost and would have to be regenerated.

b. FM Recording

In this method of recording, a current sufficient to drive the tape completely from saturation in one magnetic flux direction to saturation in the opposite magnetic flux direction is supplied to the recording head. This current alternates at a frequency set by a subcarrier oscillator. The frequency of this oscillator is caused to deviate from the normal "channel center" frequency with magnitude and direction proportional to the amplitude and polarity of the data being recorded. During the playback process, the amount of frequency deviation from the channel center frequency is converted back to a voltage whose magnitude and polarity is proportional to the frequency deviation.

The FM recording and playback process is capable of recording and recovering data signals with low frequency components down to and including dc. The FM process is also relatively insensitive to the minor imperfections in magnetic tape characteristics that cause large variations in amplitude-sensitive recording methods (Direct Recording).

c. Magnetic Recording Limitations

The article "Analysis of Magnetic Recording Fields", by G. C. Feth, in the September 1962 issue of Communications and Electronics, published by the American Institute of

Electrical Engineers gives a technical treatment of the magnetic recording process. Also Chapter 1 of Magnetic Recording Techniques, by W. Earl Stewart, published by McGraw-Hill Book Company, Inc., is recommended. The following excerpts are from this source.

"The signal-to-noise ratio that a particular system can tolerate has much bearing on how high a frequency (or short a wavelength) can be usefully recorded. In audio work, 30- to 60-db signal-to-noise ratios are commonly used for the over-all measurement. For a particular octave or fraction of the entire band, somewhat better ratios must be attained if the over-all ratio is to be maintained. For instance, a signal-to-noise ratio of 50 db cannot be accepted for the band from 10, 000 to 15, 000 cps if a signal-to-noise ratio of 50 db is desired from 50 to 15, 000 cps, since the noise from other parts of the band are certain to add something to the total noise, even if they measure 52 db below the reference level when measured separately.

"However, the same limitations do not necessarily carry over into other applications of magnetic recording. For instance, pulse recording for computer work can in many cases tolerate higher distortion, lower signal-to-noise ratios, and considerable lack of linearity, so long as the pulse can be discerned without error with a circuit tuned to a comparatively narrow band of acceptance. Thus, shorter wavelengths and recorded signal levels well below those acceptable for audio work may be usable."

* * *

"This paragraph is not intended to set any values or rules but rather to point out that the rules for audio recording should not automatically be carried over into other fields without serious questioning and testing of the applicable limits. Whereas wavelengths under 0.00005 in. appear to offer serious obstacles in audio recording, they may be very acceptable in other fields."

Basic magnetic recording limitations could be listed as head design, tape material, tape motion and head-to-tape contact. Some limitations on the recording of high frequency data can be removed by simply moving the tape across the head at a greater rate of speed (usually rated in inches per second) but this can only be useful up to the point where head design and tape characteristics become the limiting factors. Thus, not all requirements for greater and greater time resolution can be solved by simply running the tape at a higher speed.

Timing limitations due to tape motion are commonly listed under classifications of "wow", "flutter", and "dynamic skew."

"Wow" is a term used to describe a slowly varying cyclic change in tape speed. "Flutter" describes rapidly changing tape speeds and "dynamic skew" describes a tape motion in which different portions of the tape width are moving across the head with different instantaneous velocity. "Dynamic skew is preimarily of concern to multitrack recording because of the intertrack time displacements produced.

d. Time Code Recording by the Direct Record Method

The time code information used for Direct Record applications is contained in the amplitude and width of a modulated carrier frequency. The carrier frequency is typically such that 10 carrier cycles are contained in the period between leading edges of the data bits in the time code word. The data bits are then width coded with duration equal to integral numbers of carrier cycles, e.g., two carrier cycles for a data "0" and five carrier cycles for a data "1".

The amplitude of the carrier is increased from a value of three units to a value of 10 units for the duration of the coded "1's" and "0's".

The presence or absence of a width coded data bit is detected by amplitude discrimination process, consequently the level at which the time code is recorded should not be so high that compression of the 3 to 10 modulation ratio occurs, with a consequent loss in amplitude discrimination capability.

The time code should not be recorded at a level so low that the recovered time code signal is contaminated by noise. When the recovered time code information is to be processed automatically as in tape search operation, especial care should be taken to insure that the direct record process does not produce a change in the axis of symmetry between the low level (3 units) portion of the modulated carrier recording and the high level (10 units) portion of the modulated carrier recording.

Any variation in this axis of symmetry will cause the recovered playback signal to have a frequency component at the bit rate frequency and to be considerably dependent upon low frequency response characteristics of the tape playback system.

e. Time Code Recording by the FM Method

Time codes recorded by the FM method can be either the width/amplitude modulated carrier type or the width coded dc level shift type. Record/Reproduce electronics of the FM type usually cost more than the Direct Record type and, consequently, the FM type recording is usually used when low frequency and dc signal components difficult to recover using Direct Record methods are involved.

f. Multiple Usage of Time Code Record Track

The problems associated with accurate time code recording and recovery are often complicated by the fact that information other than the time code is either time or frequency multiplexed with the time code as recorded. Recovery of this data then requires special time or frequency separation equipment. Time or amplitude distortions in the recording or playback process can create interference between these two or more data forms with consequent degradation of recoverable time code information.

Time Code Recording with Strip Chart Recorders and Oscillographs

Time codes recorded by these instruments are usually of the width coded dc level shift type. Information is recorded by drawing a "line" or "trace" on the paper. When the transport speed of the recording medium is fast enough to move the medium two or more "line widths" during the shortest interval used in the time code format, the standard width coded dc level shift format is usable.

When the transport speed of the recording medium moves less than two "line widths" in the smallest code interval, then the addition of amplitude coding to the width coding improves the time code readability.

When the recording media is moved several "line widths" in the minimum time code interval, then the ability to resolve smaller time code increments and to read time points more accurately is limited by the maximum writing rate and time delay of the pen motor or event marker solenoid. One advantage of recording width coded time information is that it removes all requirements for linear amplitude response and so pen motors and event marker solenoids can have non-linear, time dependent, drive currents that produce fast writing rates with small delays. "Overshoots" that would seriously degrade amplitude modulated data recordings are of little consequence so long as the time duration of these overshoots is less than the time duration of the coding interval.

Time Code Recording on Film

Recording of time on film falls into two main areas of technique, dependent upon the type of film motion.

a. Intermittent Film Motion

One example of time recording on film with intermittent motion is the time tagging of data frames in the Askania Cine-Theodolite camera. A 35 mm film frame is exposed and after each exposure the film is shifted by a distance corresponding to the width of the aperture plate. The displacement of the target from the boresight axis of the camera is thus recorded. The Azimuth and Elevation angles which represent the angular displacement of the camera's boresight axis from a previously established reference target are projected onto a reserved area of the film frame by an auxiliary optical system. The azimuth and elevation displacement angles are obtained from precision ruled glass plate dials.

A small segment of this dial in the vicinity of the dial index and vernier index is illuminated by a short duration high intensity strobe lamp whose time of flashing is usually made coincident with an identifiable standard time point. The opening of the shutter is usually the result of a programmed shutter opening pulse whose time of generation is sufficiently early with respect to the flash pulse that an adjustable delay in the shutter control circuitry when added to the time required for the shutter mechanism to be tripped and to obtain the "full open" position, will cause the "full open" shutter position (which records the target displacement from the camera axis) to be time coincident with the flash pulse (which records the pointing angle of the camera axis).

The coded value of the standard time point at which the target and dial data were recorded must be attached to this film frame as it is being transported away from the shutter aperture area. Neon lamps with flashing rates controlled by the coded time message are used to sequentially write a series of dots on the film edge which will document the particular standard time point at which the film was exposed.

This "after the fact" attachment of the coded time message is usually accomplished by one of two techniques:

(1) Recirculation method -- The coded value of each standard time point is scanned at a bit rate that allows a minimum

of two coded messages to be scanned in the time interval that the film is in motion, thus one complete time code plus fractional positions of end and beginning of the code will always be recorded on each frame of film.

(2) Scan on demand method -- Electrical signals are derived from the camera mechanism that indicate that the film motion has started and command a single scan out of the stored standard time point value. When the start of film motion can be detected or accurately predicted, this method gives coded time in an easier-to-read form (no requirement to search for marker pulses to identify beginning of coded time message).

b. Continuous Film Motion

When film moves in a continuous motion, then one of the standard time code formats can be chosen whose bit rate allows a minimum of five resolvable increments of film motion to occur in one bit period and whose time code frame interval does not include an amount of film motion so large as to make the coded time message spread out over too lengthy a section of film.

Time codes in the width coded level shift form control the duration of flashing neon lamps. Time codes in the width coded amplitude modulated carrier form can be used to flash the neons once for each increased amplitude carrier cycle, thus IRIG B with a 1 kc carrier would produce a group of 2 dots for code "zeros," and a group of 5 dots for code "ones," and a group of 8 dots for "position identifiers."

3. Time Code Decoding and Data Processing Techniques

The study of time code decoding techniques is applicable to time code decoders, time code conversion equipment, magnetic tape search and control equipment, timing terminal equipment, or any device that accepts time code information from a phone line, radio link, or playback from a magnetic tape.

Timing as used in data processing reduction techniques is studied here because the data reduction process normally follows a decoding process.

The specific requirements and desired characteristics of a time code decoder are dependent on its use. For example, time delay inserted in the timing operation is probably the most important consideration for a time decoder in a terminal timing unit operating in real time at the end of a phone line and providing time data to recording instrumentation. Good reliability in the decoding process is probably the most important consideration in a time code decoder decoding time from the playback of a magnetic tape for insertion into an automatic data processing system.

Most present day time code decoders operate on serial time codes in a width coded amplitude modulated carrier form as received from a communication link or from the playback of a magnetic tape recorded in the direct record mode. There are decoders which operate on dc level shift codes such as dc level shift codes obtained from the playback of tapes recorded in the FM mode. Although all types of decoders will be considered, more attention will be devoted to the modulated carrier type.

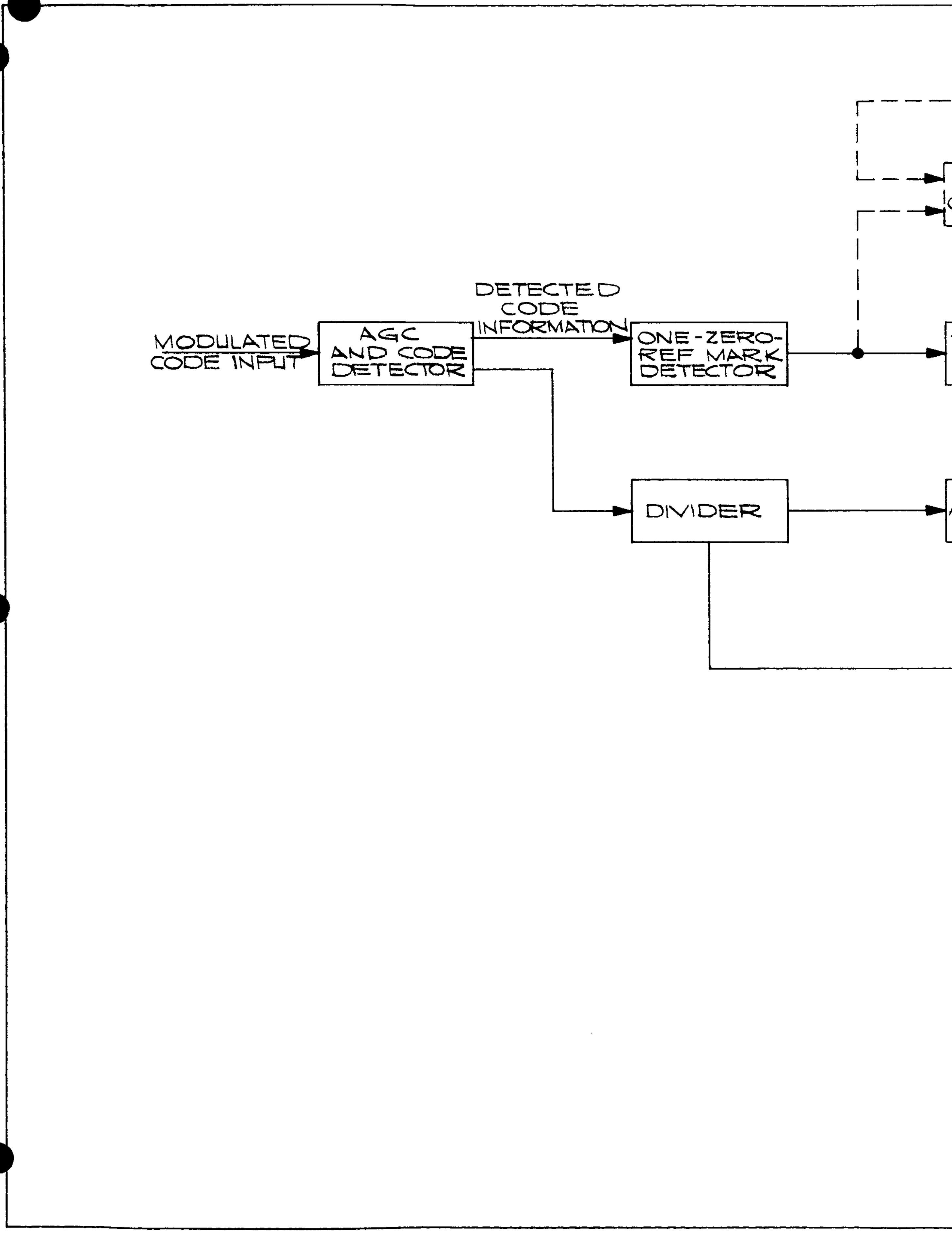
Time Code Detector

One type of time decoder which is typically used in simple timing terminal units does nothing more than demodulate a modulated carrier time code and present the code in the original dc level shift form for recording on instrumentation records such as strip chart recorders or on instrumentation cameras with neon drivers. Such a unit does not "decode" the input signal in the sense that it considers the entire code word.

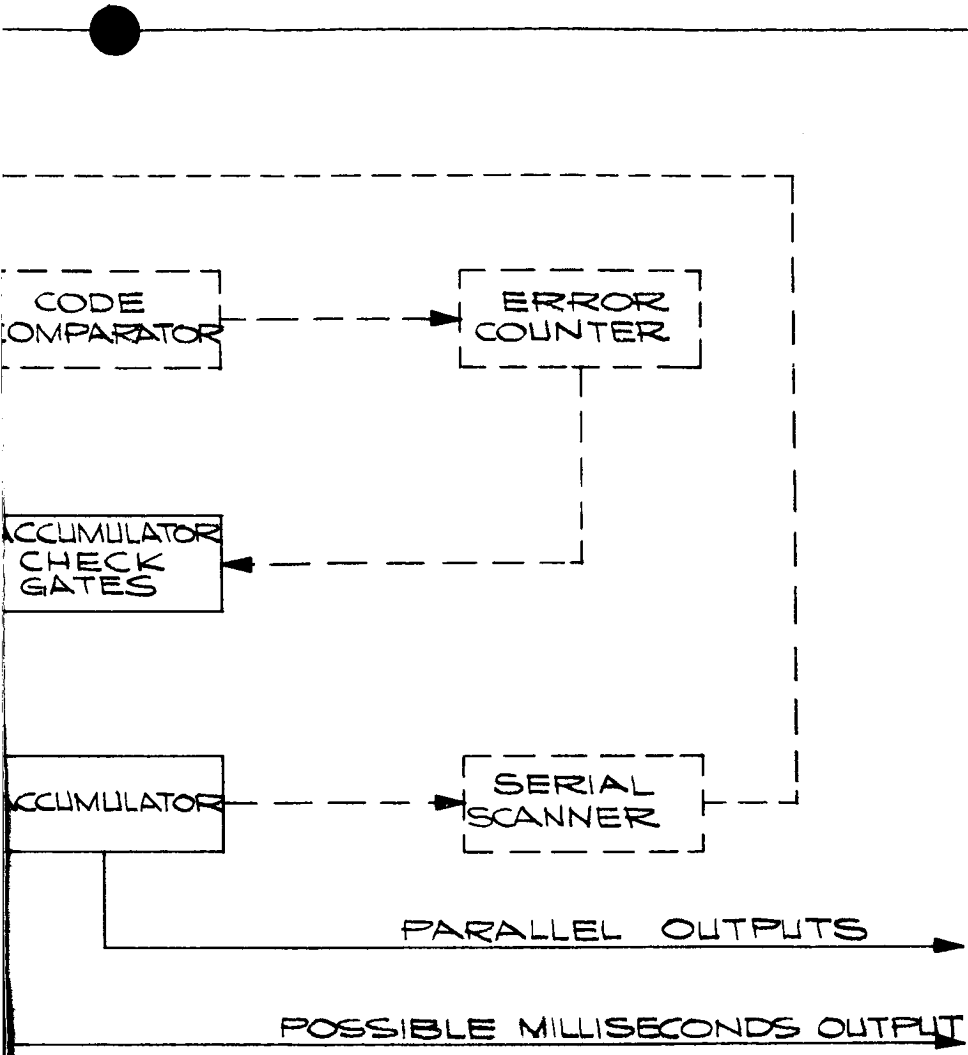
One of the main considerations with this type of unit is the detection delay which it causes; delay in detection of both the leading and trailing edges of the time code elements. Techniques including quadrature detection with minimjm filtering can minimize the detection delay.

A more commonly used system incorporating a code accumulator is used in decoding systems which require a parallel output as well as possible serial outputs, such as data processing decoders, time code conversion equipment, certain timing terminal systems, and tape search and control systems. A typical decoding system of this type is shown in figure 3.

In addition to providing AGC, the AGC and Code Detector circuit provides a detected carrier output that is a pulse for each



MODULATED CODE INPUT
AGC AND CODE DETECTOR
DETECTED CODE INFORMATION
ONE-ZERO-REF MARK DETECTOR
DIVIDER



TYPICAL TIME CODE DECODER

ELECTRONIC ENGINEERING COMPANY
OF CALIFORNIA
SANTA ANA

DWG NO.
FIG. 4

crossover of the carrier, usually 1000 cycles for time codes to be decoded from magnetic tape playback or received on a phone line. The detected carrier signal is divided down to the time code frame rate (usually 1 pps) and used to update an accumulator in the same coding as the time code.

The detected code information signal also provided by the AGC and Code Detector circuit is in the form of pulses for each high amplitude cycle of the modulated carrier. The signal is decoded into "ones," "zeros," and "reference marks" by counting the number of carrier pulses present in each width coded element. The decoded code word is used to reset the accumulator to the code word bit by bit as it is received serially.

Once the accumulator is properly synchronized to the incoming code word, it is updated by the detected carrier and is "on time" with the reference mark of each incoming code word. Each incoming code word then "checks" the accumulator bit by bit as it is received. In this system, if an error is made in detecting the code word, the accumulator will be reset erroneously and will remain in error until "cleared" by the next received time code frame. Likewise, if an error occurs in the detected carrier channel which is updating the accumulator, the error will persist in the accumulator until the following time frame is received.

A more reliable system can be implemented by adding a means of resetting the accumulator only after a preset number of consecutive errors has been detected. This is done by adding a serial scanner which samples the accumulator in synchronism with the incoming code word. The incoming code word is then compared bit by bit with the accumulator and any errors detected are stored. When the number of consecutive errors equals some preset number, the accumulator is then reset to the incoming code word.

While more sophisticated time code decoders can be developed, it is felt that the system described above is adequate for most operations, if normal reliability considerations are given to designing the system providing the input to the time decoder. It is felt that it is better practice to design extra reliability into the time code generation, distribution, and recording equipment which precedes the time code decoder than to overly complicate the decoder itself.

Time Code Translators

These devices decode and store coded time information in registers which, for a real time system, are updated with a minimum real time delay. The translator then makes this information available in an acceptable format to data recording and data formatting equipment.

The translator is essentially a serial-to-parallel time data converter with the parallel data being serially scanned out in a different format with bit rate and frame interval adjusted to the requirements of the data recording or formatting system. The translator can also modify and store the coded time information so that parallel time code information in a desired format is available to a computer or data formatting system.

When parallel information is used, a separate line is used to indicate the status of the parallel information. When the value of a multibit parallel time code is being incremented, not all of the bits that are subject to change for a particular increment will change simultaneously. The differential times between changing least valued bits and most valued bits can be of the order of one microsecond for an array of code storage devices such as "flip-flops" which have operating frequency limits of one megacycle.

The status line can be utilized in several possible modes. If the length of time required for the computer or data formatting system to read the parallel information lines and then logically disconnect itself from the lines is known, then the status line can be implemented as a "data ready" line which is placed in the "inhibit" or logic "zero" state sufficiently in advance of the incrementing of the time code count to prevent the start of a reading which could not be completed before the time data started to change. This status line is placed in the "permissive" or logic "one" state as soon as all data lines have stabilized to their newly incremented value.

If there are several users of this parallel data, and some or all of them read this data at rates asynchronous to the rate at which the code is incremented, and there is a large variation in the length of time required for each user to read the data, then the line is usually placed in an inhibit status early enough to take care of the devices with shorter read times and the devices with longer read times have to implement their own predicted inhibit times.

Time Tagging of Sampled Data

When coded time information is being used to time tag data which has been digitized for entry into a digital computer, several techniques can be used.

The first technique requires sampling the data synchronously at defined time code intervals and/or integral multiples of defined time code intervals. These data samples are then digitized and delivered to a computer, or recorded on tape, for future computer entry. As an example, if there are ten data channels, then all data channels might be sampled simultaneously at a 10 pps rate with sampling commanded by an "on time" 10 pps derived from the time code signal. Data points taken in this fashion are inherently "time tagged" and only require further time identification with a time code whose least significant digit has a weighting of 100 milliseconds to resolve the 100 millisecond ambiguity.

The second technique would be used when data channels are sampled simultaneously but at rates that are not synchronous with existing time code rates. Each data sample would then require a "time tag" with a more elaborate time code whose least significant digit has a value less than the required "time tag" accuracy.

A third technique would be used when several data channels are being sampled sequentially (scanned), and the data samples from each scan assembled into one data block for subsequent recording or computer entry. A "time word" is included in the data block to indicate the beginning of scan to the nearest coded time interval. A "flag" bit is added to the data word of any channel whose sample time occurs at or immediately after the next coded time interval. The computer program then assigns to the flagged channel a time value equal to the time word plus one time code increment and, using a known sampling rate, can assign a time value to all the other data samples (channels) in the scan (data block).

B. TASK III

1. Time Transmission from Station to Station

General

Station-to-station transmission is interpreted to mean any transmission of timing signals for distances greater than 1 mile (distances less than one mile are classified as distribution of signals within a station).

There is a definite trend at installations where there are several instrumentation sites within a few miles of each other to provide individual generators at each site rather than to provide a central generator which distributes timing signals to terminal timing units at each site. This, of course, reduces time transmission problems.

Time Transmission Via Land Lines

Land lines used for time code transmission will have the following important parameters:

a. Bandwidth (in cycles per second)

Bandwidth is usually rated as being the span of frequencies over which the transmission loss does not deviate from the frequency of minimum loss by more than 3 db. Frequency response of lines should be checked over a frequency range considerably in excess of the 3 db bandwidth to insure that there are no spurious responses outside the 3 db bandwidth spectrum.

b. Transmission Delay Time

(1) Transmission delay should be measured for all significant frequency components contained in the time code signal. When the various component frequencies contained in an amplitude modulated signal are not recombined with equal delay times, then the resultant pulse will have a different shape and a different envelope-to-carrier phase relationship.

(2) Transmission delays may show both short term variations (jitter) and long term variations (drift). Delays should be measured frequently enough and for a sufficient time span to show up daily and seasonal variations.

(3) Transmission delay time on land line circuits can be measured by several methods.

(a) The roundtrip time on a bidirectional circuit whose bandwidth - delay time product is greater than unity can be measured by the echo ranging or pulse sounding method.

(b) When two or more nearly identical circuits exist between two points, then the equivalency of the lines can be used in a loop circuit in which the round-trip circuit time, using circuits A and B, is measured and the A time is taken as one half of the A + B time.

When three circuits (A, B, and C) are available, the value of each can be determined by solution of simultaneous equations in which

$$A + B = X$$
$$B + C = Y$$
$$C + A = Z$$

and

$$A = \frac{X - Y + Z}{2}$$

$$B = X - A$$
$$C = Z - A$$

(c) Radio transmission techniques can be used to measure line transmission delays over moderate distances. A transmitter receiver combination's modulate/demodulate delay can be calibrated by the simple technique of placing the receiver at the time code generator location and measuring the time delay between the time code generator output and the receiver output. The radio receiver is then transported to the receiving terminal of the transmission line. A delay time equivalent to the additional radio propagation distance is then added to the previously measured modulate/demodulate delay to form the total radio circuit delay. The time of radio receiver output corrected for the total radio delay is then compared with the time of transmission line output to find the transmission line delay.

(d) A portable electronic clock whose basic frequency standard is sufficiently stable to provide drift rates predictable within the accuracy required, can be used to measure transmission time delay. As an example, a clock whose frequency is corrected to within 1 part in 10^{10} and whose drift rate is 1 part in 10^{9} per day will be off 2 parts in 10^{10} in 2.4 hours and will have been off frequency an average of 1.5 parts in 10^{10} over the 2.4 hour period. This will produce an accumulated time deviation of 1.5 microseconds in 10^{4} seconds or $1.5 \times \frac{8640}{10000} = 1.3$ microseconds in 2.4 hours.

to the extent that this drift pattern is predictable with a less than 8% uncertainty, the transmission delay time between two 100 mile separated points (assuming clock travel time less than 2.4 hours) can be measured to 0.1 microsecond accuracy.

(e) Precision radio signals such as Loran-C can also be used to measure transmission delays. The differential time delay between the received Loran-C signal and the generated time pulse at Station A and the Loran-C time pulse differential time at Station B corrected for the difference in Loran-C radio propagation time to Stations A and B will provide a measure of the transmission time from A to B.

(4) Amplitude detection delays in transmitted time signals. When amplitude discrimination is used to determine the presence of a code "bit" the finite bandwidth of the transmission line will increase the amount of time required for the transmitted pulse to change its amplitude by 50%. Consequently the time of voltage corssing of the amplitude discriminator threshold will be delayed by the increased "rise time" of the transmitted pulse in addition to the "transport time" delay in delivering the pulse.

c. Signal-to-Noise Ratio

The signal-to-noise ratio of a transmission line should be measured over the effective bandwidth of the timing terminal unit which detects, and decodes or regenerates the time code information. This signal-to-noise ratio measurement should show the variations of this ratio with respect to time and should be taken over a sufficient time span to include a high percentage of all time-dependent noise sources.

In addition to measuring the signal-to-noise ratio of each transmission line circuit, the spectral distribution of the noise should be measured and every effort should be made to get rid of any identifiable contributor to the general noise level.

Balanced transmission lines and balanced termination circuits which provide a large degree of "common mode" noise rejection are frequently used. The degree of "common mode" noise rejection should be measured and verified on a periodic basis.

Time Transmission Via Radio Links

Radio links used for time code transmission will have bandwidth, delay time, and signal-to-noise ratio as important parameters, but these parameters will be influenced by some factors that are different than the transmission line case.

The bandwidth occupied by a transmitted radio signal is ordinarily limited by spectrum utilization considerations. Since radio transmitting antennas are often omnidirectional or only mildly directional, the radiated signal covers a general area and the spectrum occupied by one radio link is then unusable by any other radio links in the same general area.

When the effective field strength at the receiver location is large enough to provide good signal-to-noise ratios, the receiver bandwidth can be made wide enough to include all the spectral components which make a significant contribution to the transmitted signal. However, if the field strength at the receiver location is too weak to provide good signal-to-noise ratio over a full spectrum bandwidth, then the receiver bandwidth must be narrowed to include only those spectral components that make a major contribution to the transmitted pulse. This results in an improved signal-to-noise ratio at the expense of degraded pulse rise time capability.

The time delay of a typical radio link having a 3 kc bandwidth and a circuit length of 10 statute miles will have a propagation (circuit length) delay of only 53.7 microseconds and a modulate/demodulate delay that will approach 1000 microseconds. The two major contributors (the modulator and demodulator delays) are separately measurable with test equipment at the transmitter and receiver locations and can be monitored and corrected, if necessary, on a real time or post operational basis. The propagation delay can be quite accurately calculated from the distance between transmitter and receiver antennas.

The signal-to-noise ratio deliverable to a full spectrum bandwidth receiver will primarily depend on the radiated power of the transmitted signal and the percentage of this power that is interceptable by the receiving antenna. Directivity of the transmitting antenna can increase the power per unit area at the receiver location, and the power intercepted by the receiving antenna will then be a function of the effective area of the receiving antenna. Equal signal-to-noise ratios can be delivered with a variety of different combinations of transmitted power, transmitting antenna directivity, and effective receiving antenna area. The optimum combination will vary for different installations.

Multiple Code and Rate Distribution Systems

Pulse code modulation (PCM) time division multiplex systems are used to distribute multiple time codes and pulse rates on one radio link. Typical systems will have a frame rate of 1000 frames per second. One typical system divides the 1000 microsecond frame period into 100 information channels (20 of which are unused to provide a propagation connection period). These information channels are scanned in an encoder unit at a 100 k pps rate (ten microseconds per channel). Scanning of the 100 channels produces a 100 element PCM code at the output to the encoder unit. The logic "one" or "zero" state of each of the 100 channels controls the presence or absence of a bit in the PCM encoder output. Bits present are represented by pulses of 2 microseconds duration.

This PCM code is broadcast on a suitable rf carrier and radio receiving equipment at the user's location delivers a replica of the broadcast PCM code to a synchronizer-decoder unit. This synchronizer-decoder unit reassembles the serial PCM code information into parallel data which is a replica of the data presented to the input channels of the encoder.

Time and rate data is delivered to the user "on time" by delivering to the endoder unit, data that is "early" by one frame period (1000 microsecond) plus a "maximum propagation delay" allowance of 200 microseconds.

In the decoder, each channel has a storage element (flip flop) whose status is strobed after receipt of the last (99th) data channel. This strobe is delayed from the marker time of the next data frame by the difference between the actual propagation delay and the 200 microsecond maximum delay allowance. As an example, if the receiving equipment were located at hthe maximum correctable distance (delay = 200 microseconds) then the marker of the subsequent frame would be received 1,200 microseconds later than the time at which the 1200 microsecond "early" time data was sampled by the encoder (100 microseconds frame period plus 200 microseconds propagation delay) and strobing of the stored previous frame data by the marker pulse of the next data frame would produce parallel "on time" outputs at the user's location. When the delay time to the user's location is 20 microseconds less than the 200 microsecond value, then the output data strobe must be delayed from the marker pulse of the next data frame by 20 microseconds to produce "on time" data.

An alternative method of propagation delay correction, which does not require unused channels (dead time) within the frame period, requires the use of double storage units (flip flops) for each data channel. The time displaced serialized data in each channel is accumulated in the first storage element and transferred in parallel to the second storage element at the beginning of the next frame (marker pulse time) and the array of second storage elements is then strobed at marker time plus the difference between the delay time to the user's location and the maximum delay allowance. Using this method, the maximum propagation delay correction equals one frame period and in the case of a 1000 microsecond frame period would allow propagation corrections for path lengths up to 185 statute miles.

A new timing system is currently being installed at the Air Force Flight Test Center (AFFTC) Edwards, California with initial operation scheduled for June 1965.

This system will use a 50-channel time division multiplexing system with a frame rate of 1000 frames per second. Distribution will be via a 1720 mc radio link whose transmitter is approximately 12 miles from the time code generator equipment. Timing signals are carried on coaxial cable to a microwave terminal and then transmitted via the 12 mile microwave link to the remote 1720 mc timing transmitter using the full base bandwidth of the microwave link.

The 1720 mc receiving and decoding equipment will have optional digital delay units to provide accurate delay corrections.

C. TASK IV. TIME CODE DISTRIBUTION WITHIN A STATION

Distance Definition

For the purposes of this study, the term "within a station" will be interpreted as distribution to various pieces of "using equipment" located within a radius of one mile of the time code generating equipment.

Purpose

Distribution of encoded time information makes available to several "users", time data without each user having to buy, maintain, calibrate, and synchronize a time code generator. Using equipment will include magnetic tape recorders, strip chart recorders, oscillograph recorders, photo optical recorders, as well as time selective programming equipment and time display equipment.

Time triggering of data will be simultaneous at all user locations, or will have a known time displacement.

Time Code Distribution

Items to be considered are --

(1) Protection against abnormal loading. -- When ever possible, each user of a particular time code should be connected to the time code generator through an "isolator" circuit. This can take the form of an active amplifier whose high input impedance is paralleled with other similar amplifier inputs at the TCG output or the isolator can be a multiple resistive divider

network whose input is driven by a signal many times the amplitude of the largest required signal and whose multiple outputs are individually adjustable to the desired output level. If one output is shorted, the affect on the output level of the remaining outputs is negligible.

(2) Adequate monitoring. -- When both parallel and serial time codes are being generated and distributed, reliability will be improved if the time code display used to monitor the generating equipment includes a display derived from the serial code.

(3) Adequate control of distribution system. -- The timing signals should be transmitted over restricted access circuits. All land lines and radio links carrying timing information should be under administrative control of personnel charged with timing responsibility. This would include authorization of connections and disconnections, performance of preventive maintenance, keeping of operating and maintenance records.

In cases where multiconductor cables are used, the cables should only contain sufficient conductors to supply present and reasonable predictable future timing distribution requirements. Control of the entire cable should remain under timing personnel. Spare circuits in these cables should not be assigned to non-timing functions with the consequent dilution of control.

(4) Flexibility of distribution system. -- The typical time code distribution system will include a number of "line driver" amplifiers. These units should be standard modular assemblies that are easily replaceable plug-in circuit assemblies in order to minimize circuit down time.

Cable circuits should be "patchable" wherever possible at both the sending and receiving end so that spare circuits can be rapidly substituted for operating circuits. This feature facilitates periodic circuit testing as a preventive maintenance check.

Parallel Versus Serial Time Code Distribution

Parallel coded time information requires a separate communication circuit for each bit of information contained in the coded time message. For instance, time of day that is encoded in BCD language as tens of hours, hours, tens of minutes, minutes, tens of seconds, and seconds will contain $2 + 4 + 3 + 4 + 3 + 4 = 20$ bits of information and will require 20 circuits for parallel transmission.

The most common transmission path for parallel time code information is the multiconductor cable.

Parallel time information usually requires less elaborate equipment to decode and/or display than does serially coded time.

Limiting factors on the distance over which it is desirable to transmit parallel time code information are --

(1) The greater cost of multi-wire cable.

(2) The greater cost of installing the bulkier multi-conductor cable.

(3) The amount of series resistance that can be tolerated (this can be controlled by increasing conductor size, but at the cost of increasing factors 1 and 2).

(4) Capacitive and/or inductive effects associated with lengthy cables.

(5) Crosstalk between conductors in the cables. This is usually only important if the decoding is on an ac or transitional basis.

The above limiting factors are all interdependent and also dependent upon the characteristics of the device to which the parallel time code will be delivered. Some typical examples are --

(1) Incandescent Decimal Time Display. -- Typical coding for this device divides the 10 possible lamp selections into a bi-quinary code in which numbers 1 through 5 are modified by "odd", "even" gating to select the desired one of ten lamps. This system requires 35 wires to control the remote display.

Lamps used are #1815 rated at 14 V, 0.2 A. If a 10% reduction in lamp voltage is the maximum reduction to be tolerated, then a conductor resistance of $\frac{1.4V}{0.2A} = 7$ ohms is the maximum allowable. Required conductor size in circular mil area will be 10 circular mils (1 ohm/ft) divided by allowable resistance (7 ohms) and multiplied by distance (feet) or 1.4 X circuit length in feet.

Thus, a 100-foot cable (200 foot loop) for this service must have conductors of 280 circular mil area or greater if the 10% voltage drop limit is to be met. This means #25 gauge or larger conductors. The over-all diameter of 22 gauge 54-conductor cable is approximately 0.6 inches and costs approximately $35.00 for 100 ft.

No. 22 gauge which has a cross-section of 640 circular mils and display units using #1815 lamps or similar lamps can be remoted as far as 228 ft. before the 10% voltage drop limit is exceeded.

When incandescent display devices of this type are to be remoted by 1000 or more feet, then a cable having 16 gauge or larger conductors would be required and the estimated cost of a 36-conductor cable having 16 gauge conductors would be approximately $600.00 for a 1000 ft length. This cable would have an over-all diameter of 0.75" with consequent increase in installation costs. When incandescent displays are to be remoted over distances of more than 1000 ft serial time code transmission with serial-to-parallel conversion at the receiving terminal is usually advantageous.

(2) Nixie (Neon) Decimal Display. -- Nixie type displays require smaller currents at higher voltages than incandescent displays (2 ma from a 200-volt supply) as opposed to the #1815

incandescents (200 ma at 14 V). Circuit resistances of less than 10,000 ohms have negligible effect on Nixie display circuits. Consequently, the cable costs do not increase so rapidly with distance. The inexpensive multiconductor cable having #22 gauge conductors is adequate for all practical distances (322 ohms for 10,000 foot loop). At an estimated cable cost of $300.00 per thousand feet, remote Nixie time displays using parallel information at distances up to 2000 ft would be practical.

Remote Nixie displays at distances greater than 2,000 feet would probably be more economical using serial time code. Display units capable of accepting and decoding serial time code cost approximately $1000 more than do the display units with parallel data inputs.

In cases where single circuit communications lines are already available but the multiconductor cable requires installation, then the maximum economical distance for parallel time display is reduced considerably.

Serial Time Code Distribution

(1) Serial Codes in the DC Level Shift Form. -- Distribution of these codes is usually made to strip chart recorders using pen motor or galvanometer type recording elements. These signals are typically distributed using inexpensive coaxial

cable, or shielded twisted pair cable. Serial dc level shift time codes are also modified by "neon driver" units and distributed to the timing lamps of instrumentation cameras.

(2) Loss of Precision. -- Serial time with coding increments of 10 milliseconds (100 pps bit rate) or increments of 1 millisecond (modulated 1 kc carrier) can contain recoverable time information at the generator output in increments of microseconds when steep leading edges of level shift outputs and precise phase coherency between 1 kc carrier and these steep leading edges are maintained. However, this high resolution information is usually lost in the distribution process unless the transmission circuit is a properly terminated coaxial transmission line.

(3) Coaxial Transmission Lines. -- Properly terminated coaxial lines will allow coded time signals with frequency components up to 100 kc to be transmitted distances of 5000 ft with losses of approximately 4 db.

The coaxial line provides a maximum of shielding against interfering signals and allows a relatively free choice of input power level without the usual 1 millivolt upper limit.

(4) Terminal Equipment Bandwidth. -- To minimize code distortion, all line drivers and line receivers should have sufficient bandpass to avoid distortion of the amplitude modulated carrier.

III. SECTION 2. SYSTEM ANALYSES

A. DESCRIPTION OF TIME CODE FORMATS

1. General

By a "time code" we mean a complete coded time message normally recorded with data on some type of recorder. The "time code" describes the time of occurrence of some reference point within the coded time message. When we speak of a specific time code by name, the time code characteristics such as frame interval, element readout rate, code word coding, type of coding, form of presentation, type of frame reference mark, etc., are defined by the time code name.

2. Time Codes in General Use

Table 1 is a summary sheet of the time codes which are most commonly used at the present time or have been used in the past few years. The summary sheet presents the basic characteristics of the codes such as time frame, readout rate, and time word coding. A format drawing of each time code is contained in drawing A35100 (Appendix I).

There are many time codes which have been used in the past or more specialized time codes which are in use at the present which have not been listed. The time codes which are listed represent a good cross-section of time code formats with different time frame intervals, element readout rates, time word

SUMMARY OF COMMONLY USED TIME CODES

TIME CODE	CODE WORD	DRAWING A35100 SHEET	TIME FRAME	ELEMENT RATE	TIME WORD RESOLUTION	CARRIER (MODULATED FORM)	CARRIER RESOLUTION	SPECIAL COMMENTS
NASA 36-BIT BCD TIME CODE	BCD DAY.HR.MIN.SEC	1	1 SEC	100 PPS	10 MS	1000 CPS	1 MS	CONTAINS: 4 ID BITS 100 PPS SUB-CLOCK RATE
NASA 28-BIT TIME CODE	BCD DAY.HR.MIN	2	1 MIN	2 PPS	0.5 SEC	100 CPS	10 MS	CONTAINS: 4 ID BITS 2 PPS SUB-CLOCK PULSES CAN BE INHIBITED
NASA 20-BIT BCD TIME CODE	BCD DAY.HR	3	1 HR	1 PPM	1 MIN	100 CPS	10 MS	CONTAINS: 4 ID BITS 1 PPM SUB-CLOCK RATE PULSES CAN BE INHIBITED
NASA SERIAL DECIMAL TIME CODE	DECIMAL HR. MIN. 10'S OF SECONDS	4	10 SEC	10 PPS	0.1 SEC	DC LEVEL SHIFT	-----	
IRIG STANDARD FORMAT A	BCD DAY.HR.MIN.SEC. 1/10 SEC AND STRAIGHT BINARY SECONDS TIME OF DAY	5	0.1 SEC	1000 PPS	1 MS	10.000 CPS	0.1 MS	CONTAINS: 27 CONTROL ELEMENTS
IRIG STANDARD FORMAT B	BCD DAY.HR,MIN,SEC AND STRAIGHT BINARY SECONDS TIME OF DAY	6	1 SEC	100 PPS	10 MS	1000 CPS	1 MS	CONTAINS: 27 CONTROL ELEMENTS
IRIG STANDARD FORMAT C	BCD DAY,HR,MIN	7	1 MIN	2 PPS	0.5 SEC	100 CPS OR 1000 CPS	10 MS OR 1 MS	CONTAINS: 63 CONTROL ELEMENTS
IRIG STANDARD FORMAT D	BCD DAY,HR	8	1 HR	1 PPM	1 MIN	100 CPS OR 1000 CPS	10 MS OR 1 MS	CONTAINS: 9 CONTROL ELEMENTS
IRIG STANDARD FORMAT E	BCD DAY,HR,MIN,10 SEC AND STRAIGHT BINARY SECONDS (EVERY 10 SEC) TIME OF DAY	9	10 SEC	10 PPS	0.1 SEC	100 CPS OR 1000 CPS	10 MS OR 1 MS	CONTAINS: 27 CONTROL ELEMENTS
IRIG STANDARD FORMAT F	BCD DAY,HR,MIN	10	5 MIN	1 PP5S	5 SEC	100 CPS	10 MS	NOT OFFICIALLY ADOPTED AT PRESENT TIME
AMR A1 LEVEL SHIFT AND A2 MODULATED	BINARY CODED HR,MIN	11	15 MIN	1 PPM	1 MIN	----- *1000 CPS	----- 1 MS	
AMR B1 LEVEL SHIFT AND B2 MODULATED	BINARY CODED HR,MIN,SEC	12	20 SEC	1 PPS	1 SEC	----- *1000 CPS	----- 1 MS	
AMR C1 LEVEL SHIFT AND C2 MODULATED	BINARY CODED,HR,MIN,SEC	13	1 SEC	20 PPS	50 MS	----- *1000 CPS	----- 1 MS	
AMR D1 LEVEL SHIFT AND D5 MODULATED	BINARY CODED HR,MIN,SEC	14	1 SEC	100 PPS	10 MS	----- *1000 CPS	----- 1 MS	
AMR D2 LEVEL SHIFT AND D6 MODULATED	BINARY CODED HR,MIN,SEC 0.1 SEC	15	1 SEC	100 PPS	10 MS	----- *1000 CPS	----- 1 MS	SAME AS D1 BUT HAS 10TH SECOND CODE ADDED 8 TIMES PER SECOND
AMR E1	BINARY CODED HRS,MINS,SECS	16	1 SEC	500 PPS	1 SEC (2 MS BETWEEN +6 MS AND +38 MS)	-----	-----	REFERENCE 1 PPS ON TIME IN ADVANCE OF THE FIRST PRESENCE-ABSENCE CODE DIGIT POSITION. TIME CODE BETWEEN +6 MS AND +38 MS
AMR E2	-----	16	1 SEC	500 PPS	-----	-----	-----	17 DIGIT, 500 PPS POSITION IDENTIFIERS APPEARING BETWEEN +6 MS AND +38 MS
AMR E3	BINARY CODED HRS,MINS,SECS TENTH SECS	17	0.1 SEC	500 PPS	0.1 SEC (2 MS BETWEEN +6 MS AND +46 MS)	-----	-----	REFERENCE 10 PPS ON TIME 6 MS IN ADVANCE OF THE FIRST PRESENCE-ABSENCE CODE DIGIT POSITION. TIME CODE BETWEEN +6 MS AND +46 MS
AMR E4	-----	17	0.1 SEC	500 PPS	-----	-----	-----	21 DIGIT, 500 PPS POSITION IDENTIFIERS APPEARING BETWEEN +6 MS AND +46 MS
APGC EGLIN SIGNAL #4	BINARY CODED HR,MIN,SEC	18	1 SEC	100 PPS	10 MS	1000 CPS	1 MS	MODULATED FORM ONLY. MODULATION RATIO 2:1

A35100
SHT 0.1

SUMMARY OF COMMONLY USED TIME CODES

TIME CODE	CODE WORD	DRAWING A35100 SHEET	TIME FRAME	ELEMENT RATE	TIME WORD RESOLUTION	CARRIER (MODULATED FORM)	CARRIER RESOLUTION	SPECIAL COMMENTS
APGC EGLIN SIGNAL #7 LEVEL SHIFT SIGNAL #9 MODULATED	BINARY CODED HR, MIN, 15 SEC	19	15 SEC	1 PPS	1 SEC	----- 1000 CPS	----- 1 MS	----- MODULATION RATIO 2:1
PMR PT. MUGU 16-BIT TIME CODE	STRAIGHT BINARY 2 SEC	20	2 SEC	10 PPS	0.1 SEC	1000 CPS	1 MS	
AFFTC EDWARDS CENTER FORMAT A 1000 PPS	BINARY CODED HR, MIN, SEC	21	1 SEC	1000 PPS	1 MS	-----	-----	CODE REPEATS EVERY 20 MS
AFFTC EDWARDS CENTER FORMAT B 100 PPS	BINARY CODED HRS, MINS, SECS	22	1 SEC	100 PPS	10 MS	-----	-----	REFERENCE MARK IDENTIFIED BY TWO POSITION IDENTIFIERS SEPARATED BY AN INDEX MARKER. END OF CODE SIMILARLY IDENTIFIED. USEFUL IN PROGRAMMING TAPE SEARCH EQUIPMENT
AFFTC EDWARDS CENTER FORMAT C 1 PPS	BINARY CODED HRS, MINS	23	1 MIN	1 PPS	1 SEC	-----	-----	
WHITE SANDS G-1 FORMAT	BCD HUNDREDS, TENS, UNITS, TENTHS SECS	24	0.1 SEC	1000 PPS	1 MS	-----	-----	CODE BITS IDENTIFIED BY MISSING ELEMENTS AT THE 3rd, 8th, 13th, AND 18th INDEX COUNTS WITHIN EACH DECIMAL TIME FRAME
WHITE SANDS G-2 FORMAT	BCD TENS OF THOUSANDS, THOUSANDS, HUNDREDS, TENS, UNITS SECS	25	1 SEC	100 PPS	10 MS	-----	-----	SIMILAR TO G-1, EXCEPT CODE BITS IDENTIFIED BY THREE 0.5 MS WIDE PULSES AT 3rd, 8th, 13th AND 18th INDEX COUNTS IN A DECIMAL FRAME
WHITE SANDS G-3 FORMAT	BCD TENS OF THOUSANDS, THOUSANDS, HUNDREDS AND TENS SECONDS	26	10 SEC	10 PPS	0.1 SEC	SEE SPECIAL COMMENTS		SIMILAR TO G-1, EXCEPT EACH BASIC ELEMENT CONSISTS OF FIVE 0.5 MS WIDE PULSES AT 1 MS INTERVALS. MODULATED CARRIER IS NOT NORMALLY USED. A SPECIAL APPLICATION UTILIZES 0.1 SEC INDEX MARKERS 4.5 MS WIDE. THE PULSE TRAIN IS USED TO AMPLITUDE MODULATE A CARRIER FREQUENCY.
WHITE SANDS G-4 FORMAT	BCD TENS OF THOUSANDS, THOUSANDS AND HUNDREDS SECS	27	100 SEC	1 PPS	1 SEC			SIMILAR TO G-3. MODULATED CARRIER NOT USED
WHITE SANDS G-8 FORMAT	BCD TENS, UNITS AND TENTHS SECS	28	0.1 SEC	100 PPS	.01 SEC			
VELA	BCD YEAR, DAY-OF-YEAR, AND TIME-OF-DAY IN HRS, MIN AND SEC	29	1 MIN	1 PPS	1 SEC	10, 60, 100, 240, OR 480 CPS	DEPENDENT UPON CARRIER FREQUENCY	SIMILAR TO IRIG C EXCEPT MOST SIGNIFICANT DIGIT FIRST AND YEAR CODE ADDED
NBS TIME CODE FORMAT WWVB	BCD DAY-OF-YEAR, TIME-OF-DAY IN HRS, MIN, SEC. UT2 CORRECTION IN HUNDREDS, TENS, AND UNITS MILLISECONDS	30	1 MIN	1 PPS	1 SEC	60 KC	16.7 MICROSECONDS	
PHILCO TYPE A	16-BIT BINARY TIME-OF-DAY IN SECONDS	31	4 SEC	20 PPS	50 MS	1 KC	1 MS	
PHILCO TYPE B	17-BIT BINARY TIME-OF-DAY IN SECONDS PLUS 5 BIT BINARY DAY-OF-MONTH	32	1 SEC	25 PPS	40 MS	1 KC	1 MS	
EECO 858 LEVEL SHIFT	20-BIT BCD TIME-OF-DAY CODE IN HOURS, MINUTES, AND SECONDS	33	5 SEC OR 60 SEC	10 PPS OR 1 PPS	0.1 SEC OR 1 SEC	-----	-----	AMPLITUDE AND PULSE WIDTH CODED, LEVEL SHIFT ONLY

A35100
SHT 0.2

coding, form of presentation, type of reference mark, etc.

Status of Existing Time Codes

Of the 33 time code formats listed in table 1, the IRIG family of codes has the greatest usage. All of the national ranges and service ranges have switched or are presently in the process of switching to the IRIG codes for all operations involving timing as a result of the Department of Defense directive to the three services in September 1960.

Some of the ranges have switched or are switching over completely to IRIG codes while others are generating certain of their old range codes in addition to the IRIG codes where projects exist which require the old codes. In most cases, however, the plan is to phase out the old range codes when these projects have been completed.

AFETR, Cape Kennedy. The new generation system being delivered to AFETR generates the complete IRIG family of codes and the complete family of AMR codes. Present plans are to generate the AMR codes as long as there is a need.

APGC, Eglin Air Force Base. The new generation time code generators at Eglin generate IRIG A, B, C, and D formats as well as a 27-bit parallel code which consists of 17 parallel bits of straight binary seconds and 10 parallel bits of milliseconds time of day. The old Eglin time generators are still in operation but will be phased out as funds are available for additional new generators.

PMR, Point Mugu. PMR has switched completely to the IRIG family of codes.

AFFTC, Edwards Air Force Base. The new generation Range Timing System which is presently being delivered to Edwards will generate all of the IRIG codes. Only the Format A code and the specialized Askania theodolite code from previous AFFTC codes will be retained in the new system. The AFFTC Format A code will be discontinued as soon as specific needs no longer exist.

WSMR, White Sands. The new generation timing system generating the IRIG codes has been in operation since March of 1962. This system generates only the G2 code of the old WSMR family of codes since it is required in present programs.

NASA Operations. The new timing system being installed at the NASA Launch Operations Center at Merritt Island will generate the IRIG codes and most of the AMR codes. It is estimated that the AMR codes will be generated for approximately two years and will then be phased out in favor of the IRIG codes.

The central time generator at the NASA Marshall Space Flight Center at Huntsville generates IRIG A, B, and C codes and AMR B_1, D_1, and D_5 codes.

The NASA orbital satellite tracking stations operated by NASA Goddard (the MINITRACK network) utilize the NASA serial-decimal code and the NASA 36-bit BCD code.

The NASA deep space program managed by JPL uses the NASA family of BCD codes.

The range codes plus several special codes such as the VELA code, the NBS WWVB code, the Philco Type A and Type B codes, and the EECO 858 code are listed as examples of special-purpose codes. All of these codes will be used as examples in the following discussions of time code characteristics.

3. Time Code Characteristics

a. Rate Characteristics

The time code frame interval and readout rate of the elements which make up a time code frame are dictated primarily by the rates of the test data which is recorded on an instrumentation recorder. The speed of the recording medium (magnetic tape speed, chart or oscillograph paper speed or camera film speed) should be determined by the characteristics of the primary data to be recorded and not by the data time tag. Therefore, timing information must be available with several element readout rates to provide proper timing data for the many types of recording systems generally used at a given facility.

This basic requirement for time codes with several different frame intervals and element readout rates is the basic reason for "families" of time codes. For example, the NASA family of codes contains three codes providing frame intervals of 1 second, 1 minute, and 1 hour with element readout rates of 100 pps, 2 pps, and 1 ppmin, respectively. This is a factor of 60 in the interval between the 1-second code and 1-minute code and between the one minute code and the one hour code. The IRIG family of codes (including the proposed Format F) provides frame intervals from .1 sec to 1 hr (readout rates from 1000 pps to 1 ppmin) with six codes. The AMR family of codes provides frame intervals from .1 sec to 15 minutes (readout rates from 500 pps to 1 ppmin) with six basic codes.

The table below tabulates these three families of codes, along with the old AFFTC codes and the WSMR G codes, indicating the ratio between the frame interval of each code in the family to the frame interval of the next slowest code in the family.

TABLE 2. Time Code Frame Intervals

Code	Frame Interval	Interval Ratio
NASA 36 Bit	1 sec	60
NASA 28 Bit	1 min	60
NASA 20 Bit	1 hr	
IRIG A	.1 sec	10
IRIG B	1 sec	10
IRIG E	10 sec	6
IRIG C	1 min	5
IRIG F*	5 min	12
IRIG D	1 hr	
AMR E3	.1 sec	10
AMR C_1, D_1, E_1	1 sec	20
AMR B_1	20 sec	45
AMR A_1	15 min	
AFFTC A and B	1 sec	60
AFFTC C	1 min	
WSMR, G-1 and G-8	.1 sec	10
WSMR, G-2	1 sec	10
WSMR, G-3	10 sec	10
WSMR, G-4	100 sec	

* Proposed.

The optimum number of codes (and the optimum frame intervals and element readout rates of these codes) for any given facility depends on the data rates to be recorded and, hence, the range of instrumentation recorder speeds in use at that facility. A time code frame rate should be selected for a given recorder speed to provide two complete time frames over that portion of the record which can be conveniently analyzed at a time. The element readout rate should be fast enough to provide the time resolution required, but not be so fast that the code word cannot be read due to crowding.

The duration of tests performed also influences the desired code frame rate, e.g., if tests with a probable duration of 1 second are to be time tagged then a time code with a frame time of one-half second or less must be used to insure at least one full time code frame during the test.

Most instrumentation recorders provide selectable recording speeds with ratios of between 2 to 5 from one speed to the next, with the greatest majority providing speed ratios closer to 2:1. Standard magnetic tape speeds, of course, are provided with a ratio of 2:1 from one speed to the next. Sweep speeds on a typical oscilloscope are provided with ratios of 2:1 and 2.5:1 from one sweep speed to the next. Some typical values are shown below.

TABLE 3. Typical Recorder Speeds

Magnetic Tape Speeds

Standard magnetic tape speeds are in the ratio of 2:1 from one speed to the next.

1-7/8, 3-3/4, 7-1/2, 15, 30, 60, 120 ips

Oscillograph Paper/Film Speeds

Model X

Speed	Ratio
.1 ips	
	4.0
.4	
	2.0
.8	
	1.25
1	
	1.6
1.6	
	2.5
4	
	2.0
8	
	1.25
10	
	1.6
16	
	2.5
40	
	2.0
80	
	2.0
160 ips	

Model Y

Speed	Ratio
.1 ips	
	2.0
.2	
	2.0
.4	
	2.0
.8	
	1.25
1	
	1.6
1.6	
	1.25
2	
	2.0
4	
	2.0
8	
	1.25
10	
	1.6
16	
	1.25
20	
	2.0
40	
	2.0
80	
	2.0
160 ips	

Model Z

Speed	Ratio
1 cm/hr	
	2
2	
	2.5
5	
	2.0
10	
	2.5
25	
	2.0
50	
	2.5
125	
	2.0
250 cm/hr	

Strip Chart Recorder Paper Speeds

Model X

Speed	Ratio
.4mm/sec	
	2.0
.8	
	2.5
2	
	2.0
4	
	2.5
10	
	2.0
20	
	2.5
50	
	2.0
100mm/sec	

Model Y

Speed	Ratio
.25mm/sec	
	2.0
.50	
	2.0
1	
	2.5
2.5	
	2.0
5	
	2.0
10	
	2.5
25	
	2.0
50	
	2.0
100mm/sec	

Typical Oscilloscope Time Bases

Sweep Speed	Ratio
.1 µsec/cm	
	2.0
.2	
	2.5
.5	
	2.0
1	
	2.0
2	
	2.5
5	
	2.0
10	
	2.0
20	
	2.5
50	
	2.0
100	
	2.0
200	
	2.5
500 µsec/cm	

Sweep Speed	Ratio
500 µsec/cm	
	2.0
1 ms/cm	
	2.0
2	
	2.5
5	
	2.0
10	
	2.0
20	
	2.5
50	
	2.0
100	
	2.0
200	
	2.5
500 ms/cm	
	2.0
1 sec/cm	
	2.0
2	
	2.5
5 sec/cm	

It would seem from these considerations that, if all other constraints were removed, it would be desirable to provide a family of time codes with an interval ratio in the order of 2 or 3:1 to provide maximum timing resolution over the complete range of data rates and instrumentation record speeds. Time generators to generate such a large number of time codes would be considerably more expensive than the present 4 to 6 rate generators. (Fourteen code rates would be required to cover the range from a .1 sec time frame to a 1 hr time frame.) A separate scanner is required for each code rate to be generated (if all rates are to be generated simultaneously). The number of code format frame intervals and element readout rates for a family of time codes to cover the complete range of data rates is limited primarily by cost and complexity of the generation equipment.

A factor which dictates the particular frame intervals and element readout rates for a given family of time codes is the coding of the particular family. Time frame intervals and readout rates should be "logical" subdivisions or multiples of the coded intervals in the formats for ease in data reduction. Since the second is the universal unit of time, it is the most common time code frame interval. The code with the 1 second time frame is the most commonly used code in each family of codes listed in table 1.

Since fractions of seconds are usually expressed in decimals it is "logical" to subdivide frame intervals of 1 second or less into decimal parts, providing synchronous subrates of 10 pps, 100 pps, 1000 pps, and 10,000 pps for use in generating the complete time code frame (generating index markers, code elements, providing a carrier for modulation, etc.). This decimal subdivision of the one second time frame is especially "logical" in time code words coded in Binary-Coded-Decimal coding such as the IRIG A and IRIG B formats.

For frame intervals greater than 1 second, the logical combinations of frame intervals and element readout rate are also dependent on the coding of the time code word. In time codes coded in days, hours, minutes and seconds, the "logical" intervals are hours, minutes (or intervals of 5 or 10 minutes) and seconds (or intervals of 5, 10, or 15 seconds).

Both the NASA family of BCD codes and the original set of four IRIG codes (A, B, C, and D) contain codes with frame intervals of 1 sec, 1 minute, and 1 hour; all logical intervals for the coding involved, but with a factor of 60 from one code to the next. The IRIG group determined that there was a need for a code between Code B and Code C and have adopted

Code E with a 10-second frame and an element readout rate of 10 pps. Code F, with a 5-minute frame and an element readout rate of 1 pp5s, has been proposed to fill the gap between Code C and Code D. These frame intervals and readout rates are all "logical" intervals for codes coded in days, hours, minutes, and seconds.

The old White Sands Missile Range family of G codes provides time formats coded in seconds, with frame intervals of .1, 1, 10, and 100 seconds. These are logical intervals for such coding and provide time frames separated by a factor of 10 from each other.

Although the ultimate time code system would have codes spaced with a ratio of 2 or 3 to 1, the only existing families of codes which provide interval ratios in the range of 10:1 are the IRIG codes and the WSMR G codes.

A family of time codes with a 10:1 separation between code intervals provides adequate coverage with a moderate number of codes. In the worst case, a given time format would provide a time resolution which was either greater or less than the ultimate resolution by a factor of 3.16 or less (the geometric mean between 1 and 10).

It is feasible, of course, that such a deviation from the ultimate resolution would not be acceptable for some special operation.

For example, it may be desired to record data during each pass of a satellite on a strip chart recorder on a routine basis, day after day for a considerable period of time. In such a situation, it would not be reasonable to use a speed three times that required to properly record the data involved, generating a record three times longer than necessary in order to use a standard time frame. In such an operation, it might be desirable to generate a special time frame designed specifically for the operation involved.

Another characteristic of time code factors which is related to the frame interval and element readout rate is the fraction of the frame interval which is occupied by the time word itself. By "time word," of course, we mean the portion of the time frame which is coded to identify the time of occurrence of the reference mark at the beginning of each frame, including any position identifiers, item separators, or index markers which might be present to separate the various elements of the time word.

In general, time code formats in which the time word is read out in a small percentage of the total time frame usually contain position identifiers and index markers which "fill" the remaining portion of the frame, providing more code elements than are required to present the code word. The increased number of elements provides increased time resolution, requires greater bandwidth for transmission, and can require additional circuitry in the generator.

Some of the time codes listed contain the time code word in the first portion of the time frame with position identifiers and index marker elements filling the remaining portion of the frame. The AFFTC, Edwards Air Force Base Format B (sheet 22) is typical of this type of format. In this format the time word occupies 18 elements of a 100-element frame. This type of code is useful in situations where the time code for each frame must be assembled and stored shortly after the start of the frame for parallel presentation to real time data systems, parallel displays, photo theodolites, etc. When the terminal equipment contains an accumulator which is incremented by the reference marker and checked for accuracy by the remainder of the code elements, a code with a high percentage of the frame devoted to the time word can be used.

Other formats which provide many extra elements than those required to generate the time word present the various portions of the time word interspersed throughout the frame with the extra position identifier and index marker elements separating each group of coded elements. The NASA family of codes (especially the 36-bit code, sheet 1) is typical of this type of format. Here the code word requiring 36 bits is spread over the first 84 bits of a frame consisting of 100 elements. Such a code provides little time in the frame for parallel presentation of the assembled word.

Still other formats listed provide only the elements required to present the time word which occupies the entire frame. The APGG, Eglin Signal No. 7 (sheet 19) is typical of this type of code. In this code all 14 elements are used to form the time word and the reference mark. Codes such as this provide minimum time resolution but require minimum bandwidth for transmission.

Several codes and families of codes use portions of the time frame to present or transmit other data such as special identification and control bits. The IRIG family of codes each provide several bits for control functions. IRIG Formats A, B, and E provide an auxiliary time word in the last 80% of the time frame as well as the control bits.

The following table shows the configuration of the time frames of the codes listed in table 1.

TABLE 4. Percentage of Frame Occupied by Time Word

Time Code	Dwg. A35100 Sheet Number	Time Frame	Percentage of Frame Occupied by Time Word
NASA 36-Bit	1	1 sec	84%
NASA 28-Bit	2	1 min	53%
NASA 20-Bit	3	1 hr	73%
NASA Serial Decimal	4	10 sec	50%
IRIG A	5	0.1 sec	50% (BCD Time Word)
IRIG B	6	1 sec	42% (BCD Time Word)
IRIG C	7	1 min	35%
IRIG D	8	1 hr	70%
IRIG E	9	10 sec	42% (BCD Time Word)
*IRIG F	10	5 min	70%
AMR A1 and A2	11	15 min	74%
AMR B1 and B2	12	20 sec	85%
AMR C1 and C2	13	1 sec	85%
AMR D1 and D5	14	1 sec	18%
AMR D2 and D6	15	1 sec	95% (.1 sec identified through frame)
AMR E1 and E2	16	1 sec	3.8%
AMR E3 and E4	17	.1 sec	46%
APGC, Eglin Signal #4	18	1 sec	18%
APGC, Eglin Signal #7 and #9	19	15 sec	100%
PMR, Point Mugu 16-Bit	20	2 sec	80%

TABLE 4. Percentage of Frame Occupied by Time Word (Cont'd)

Time Code	Dwg. A35100 Sheet Number	Time Frame	Percentage of Frame Occupied by Time Word
AFFTC, Edwards Format A	21	1 sec	100% (Time Word repeated 50 times in each frame)
AFFTC, Edwards Format B	22	1 sec	18%
AFFTC, Edwards Format C	23	1 min	20%
White Sands G1	24	.1 sec	80% (Time Word in last portion of frame)
White Sands G2	25	1 sec	100%
White Sands G3	26	10 sec	80% (Time Word in last portion of frame)
White Sands G4	27	100 sec	60% (Time Word in last portion of frame)
White Sands G8	28	.1 sec	100%
VELA Code	29	1 min	64%
NBS WWVB	30	1 min	55% (Time Word only)
Philco Type A	31	4 sec	20%
Philco Type B	32	1 sec	88%
EECO 858 (10 pps)	33	5 sec	48%
EECO 858 (1 pps)	33	60 sec	38%

b. Time Code Coding

Code Weighting

The type of coding used in a time code message is dictated primarily by the techniques to be used in the data reduction process. The time codes listed in table 1 and illustrated in drawing A35100 present time code formats coded in pure decimal hours, minutes, and seconds; binary coded decimal (BCD) days, hours, minutes, and seconds; BCD seconds; binary coded hours, minutes and seconds (grouped binary), and straight binary seconds.

The most basic factor in the data reduction process is whether the recorded data will be reduced automatically or manually; by machine or by human operators. In general, people are more familiar with decimal numbers and therefore prefer decimal or BCD coding. Most computer operations can be done more efficiently with straight binary coding.

This was a fundamental point of disagreement among the members of the IRIG timing group during their work in generating the present IRIG Standard Time Formats. Compromise time code formats were generated which contained BCD coding for manual data reduction and straight binary coding for automatic reduction.

Only the faster IRIG codes (A, B, and E) contain the straight binary words, since these are the codes which will normally be used in an automatic data reduction process. The "slow codes" (C, F, and D) are used on records which will normally be reduced by humans.

The AMR, the APGC, and the AFFTC families of codes are coded in binary coded hours, minutes, and seconds (called grouped binary). This coding is a good compromise between ease of decoding by humans and decoding by machine. A person can learn to decode binary numbers up to 59 with adequate training. It is time consuming for a person to decode binary numbers much higher than this. A computer, of course, can be programmed to decode any type of coding but the extra program steps required to convert time words from decimal, BCD or grouped binary coding to straight binary coding used in most computers requires extra computer time. The AMR grouped binary codes provide coding which can be decoded by people and require a minimum amount of conversion in the computer.

The IRIG family of codes with the separate BCD code word for reduction by people and straight binary code word for reduction by machines provides certain advantages. The BCD code is more easily reduced by people than the grouped binary code and the straight binary word is optimum for machine reduction.

An important factor which influences the type of coding of a timing system is the suitability of the time code for visual displays in both local and remote positions. Decimal displays are optimum since they can be read at a glance. BCD codes, of course, are especially suited for driving several types of decimal displays. Grouped binary or straight binary codes can be converted to BCD for display, but this process adds additional complexity and cost to generation and decoding equipment.

Other factors which influence coding to a lesser degree than data reduction and display are ease of generation, suitability for transmission and distribution, and code comparison. The most important factor here is the number of bits in the coded word and, therefore, the bit rate required. The number of bits in a time code influences the cost of generation and comparison (if done on a parallel basis). The number of bits affects time code transmission by dictating bit rate and the band width required to transmit the coded message. Time of day in straight binary seconds requires 17 bits, grouped binary also requires 17 bits for time of day in hours, minutes, and seconds. BCD coding requires a minimum of 20 bits if only the required bits are used in the tens seconds, minutes, and hours digits. Most BCD codes, however, include all four bits in all decades, using 24 bits for the coded message. Pure decimal time of day coding in hours, minutes, and seconds would, of course, require a minimum of 32 bits without any identification bits.

The following table categorizes the time code formats presented in table 1 by type of coding used.

TABLE 5. Time Format Coding

Pure Decimal Coding

NASA Serial Decimal

Binary Coded Decimal Coding

NASA 36-Bit, 28-Bit, and 20-Bit Codes

IRIG A (Also contains straight binary seconds)
IRIG B (Also contains straight binary seconds)
IRIG C
IRIG D
IRIG E (Also contains straight binary seconds)
*IRIG F

White Sands G1, G2, G3, G4, and G8 Codes
(BCD seconds - 1242 coding)

VELA Code

NBS WWVB Code

EECO 858 Codes

Grouped Binary Coding

AMR A, B, C, D, and E Codes

APGC, Eglin, Signal #4, #7, and #9

AFFTC, Edwards, Formats A, B, and C

Straight Binary Coding

PMR 16-Bit Code

Philco Type A and Type B Codes

Form of Coding

By "form of coding" we mean the technique for identifying the various elements of the time code format such as "ones," "zeros," "index markers," and "reference markers." The common forms of coding of time code messages are width coding, presence-absence coding, pulse position coding, pulse amplitude coding, and bipolar coding.

The important factors which dictate the type of coding which should be used are (1) the type of instrumentation recorder to be used, and (2) the nature of the decoding and data reduction techniques, and (3) transmission and distribution techniques.

It is our opinion that magnetic tape is the recording medium used to record the greatest portion of data when all of the various data acquisition activities which utilize coded time messages are considered, and that the data normally recorded on magnetic tape has the greatest value. If this statement is true, then it follows that considerations involving recording of time signals on magnetic tape should carry the greatest weight in determining the nature of those time signals.

Timing data is normally recorded on magnetic tape either (1) on a so called "direct record" tape channel in the width coded form with an amplitude-modulated carrier, or (2) recorded by applying the time signal to a standard VCO (voltage controlled oscillator) the output of which is mixed with other standard IRIG FM signals and recorded on magnetic tape using a direct record channel.

All of the codes listed in table 1 are width coded with the exception of the NASA serial decimal code, the AMR E codes, and the WSMR family of G codes. The NASA serial decimal code is generated with presence-absence coding. The AMR E codes are presence-absence coded, requiring an identifier channel. The WSMR G-2 code (the code normally recorded on magnetic tape) is coded by representing a zero by a single one-half millisecond wide pulse, a one by three pulses, and a reference mark by five pulses. This coding, however, can be thought of as a specialized form of width coding.

The reasons that the width coded form with an amplitude modulated carrier has been so widely accepted when recording on direct record tape channesl are (1) the signal is compatible with the direct record channel band width (no dc component), (2) the time code can be reliably decoded on tape playback by counting a minimum number of carrier cycles to detect coded "ones," "zeros," reference marks and index marks, and (3) the time code can be decoded with a tape speed-up on play-back in a tape search operation.

There has been a definite trend in the last few years to record time codes on magnetic tape by means of a VCO using the standard IRIG channels. Although the basic reason for using this technique is to conserve tape channels (the output of the time code VCO can be mixed with several other standard FM channels on the same tape track) there are other advantages. The VCO channel can accept either a dc level shift code or a modulated carrier type code since the dc component of the code is preserved. The modulated carrier form of the time signal can be decoded somewhat more reliably with this technique than it can using the direct record technique.

The direct record tape channel suffers somewhat from reduced low frequency response which causes some waveform distortion. This problem has been accentuated in the last few years in the newer magnetic tape recording equipment. The emphasis in these new recorders has been to increase the high frequency response with higher tape speeds and better head and electronics design. While these goals have been achieved, the low frequency response has suffered somewhat.

The main disadvantage of using the VCO technique is that the tape cannot be searched at tape speeds other than the record speed without the use of complicated equipment in the playback operation.

Width coded time signals in the dc level shift form can also be recorded on strip chart recorders, oscillographic recorders, and on camera film with results equal to or better than other forms of coding.

Width coded signals are desirable for recording on the typical strip chart recorder because the signal can either be recorded on one of the data pen motors or can be recorded by means of the typical on-off event marker leaving all data channels for data recording. Bipolar codes and pulse amplitude codes can be recorded on the data pen motor channels but cannot be recorded on the usual unidirectional event marker.

Either pulse width coding or bipolar coding is acceptable for time code recording on an oscillographic recorder since one of the normal data galvanometers is normally used for the time code message. The choice of one of these forms of coding over the other is a matter of personal preference.

A combination of pulse width and pulse amplitude coding provides a code which is easily read when recorded on strip chart recorders and oscillographs. The EECO 858 codes (sheet 33) are examples of this type of code.

Width coding in the dc level shift form is the most acceptable form for recording serial time code on continuous moving film in instrumentation cameras. Here the width coded dc level shift signal is normally used to turn a neon bulb on and off encoding wide and narrow areas on the continuously moving film.

A time code word generated in the width coded form is easily converted to the bipolar pulse position pulse form if desired. In this form, only the leading and trailing edges of the width coded form are generated as pulses; the leading edge of each element as a pulse of one polarity, and the trailing edge as a pulse of the other polarity. Such a signal is not normally recorded in this form, but is sometimes used for transmission or distribution over ac-coupled channels such as phone lines, and reconstituted as pulse width signals on the receiving end.

Width coding is not acceptable where the per cent variation in speed of the recording medium approaches one-half of the difference in per cent of bit period used for code identification. For example, time information is normally placed on the film in certain phototheodolites as the film is advancing from one frame to another. The film is accelerated from a set position resulting in a non-linear film movement. Time code is normally placed on such film with a presence-absence coding on one neon bulb with a set of coincident index marks on a second bulb.

c. Reference Mark Coding

The reference mark (or frame mark) of a time code format is the point in time identified by the code word presented in that frame. The reference mark should be coded in such a manner that it is readily decoded when the time message is reduced either manually or by machine. The reference mark should be coded in such a way that when recorded on magnetic tape it can be detected by automatic decoders in both forward and reverse playback. The reference mark must, of course, contain unique coding to provide means of separating it from the other time code elements. Since the reference mark is the most imporatnt element in the code word, redundancy in reference mark coding is justified to ensure reliable decoding.

There are many types of reference mark coding represented in the codes listed in table 1. The codes listed contain reference marks consisting of (1) single elements which are either wider or narrower than the other code elements, (2) a combination of several elements, and (3) several missing elements.

The "on time" mark in the codes listed is also identified in several ways including (1) the leading edge of the reference mark, (2) the trailing edge of the reference mark, and (3) the leading edge of the code element immediately following the reference mark.

The following table shows the nature of reference mark coding in the codes presented in table 1.

TABLE 6. Reference Mark Coding

CODE	TYPE OF REFERENCE MARK	ON TIME MARK
NASA 36-Bit, 28-Bit, 20-Bit Codes	5 sequential position identifiers	Leading edge of code element following reference mark
NASA Serial Decimal	5 sequential position identifiers	Leading edge of code element following reference mark
IRIG Codes	2 sequential position identifiers	Leading edge of second position identifier
AMR A, B, C, and D Codes	Single wide element	Leading edge of reference mark
AMR E Codes	No reference mark contained in code	--
APGC, Eglin Signals #4, #7, and #9	Single wide element	Leading edge of reference mark
PMR 16-Bit Code	Single narrow element	Leading edge of reference mark
AFFTC, Edwards Format A	3 sequential position identifiers	Leading edge of third position identifier
AFFTC, Edwards Format B		
AFFTC, Edwards Format C		
White Sands G1, G3, and G4 Codes	Special group of missing elements	Leading edge of reference mark.
White Sands G2 Code	2 sequential position identifiers (P.I. is a group of 5 half-millisecond pulses)	Leading edge of first position identifier

Table 6. Reference Mark Coding (Cont'd)

CODE	TYPE OF REFERENCE MARK	ON TIME MARK
White Sands G8 Code	Single wide code element (consisting of three half-millisecond pulses.	Leading edge of reference mark
VELA Code	2 sequential position identifiers	Leading edge of second position identifier
NBS WWVB Code	2 sequential position identifiers	Leading edge of second position identifier
Philco Type A Code	Single wide element	Trailing edge of reference mark
Philco Type B Code	Single narrow element	Trailing edge of reference mark
EECO 858 Codes	2 sequential position identifiers	Leading edge of first position identifier

d. Position Identifiers and Index Marks

Many time code formats incorporate Position Identifier elements and Index Marker elements to aid in the process of reading and decoding the time word. Position identifiers are elements in the time code format which are used to separate and identify portions of the time word. Index markers are the uncoded interpolating elements normally used to fill time slots in the time code format which are not used in the time code word.

The use of position identifiers and index markers in a time code format aids in the reduction process of certain types of codes. For example, many position identifiers and index markers are used in codes with BCD coding, since the code word is naturally divided into several decades. Fewer position identifiers are used in codes with grouped binary coding, since there are fewer natural groups in the format. No position identifiers need be used in a code word with straight binary time of day in seconds, since there is but one group of elements in the code word.

B. ANALYSIS OF TIME CODE FORMATS

1. General

The following analysis of time code formats is based on the general background material presented above. The purpose of the analysis is to compare the various factors involved in time code formats and to make recommendations for the characteristics that an optimum family of time codes should possess to provide a set of codes for a wide variety of instrumentation applications.

2. Recycle Interval of Basic Code Format

A time code to be used to provide time data to several operations simultaneously and involving operations with a wide range of durations must provide continuous time identification for a period of time sufficient for the longest operation. The recycle interval should be compatible with the UT-2 time scale -- the scale used in all general activities. In the early days of range instrumentation and data acquisition, most operations could be completed within 1 day and, therefore, most of the early range codes recycled each day. Since many present operations (especially orbiting satellites and deep space probes) are of several months duration, one year is the most reasonable interval to be uniquely identified in a time code format.

The IRIG family of codes and the NASA family of codes provide a one-year recycle time. The VELA code is the only code listed in table 1 (sheet 29) which has a recycle interval greater than one year. A recycle interval of ten years is reasonable for time tagging the long period seismic data recorded in Project VELA.

3. Time Code Frame Configuration.

Information/Bandwidth Efficiency of Time Code Formats.

In all of the existing time code formats, the complete time word is transmitted in every frame. For example, in the IRIG A format the one-tenth second time frame contains all of the bits of the code word from the tenth-second bits through the days-of-year bits. From an information theory point of view, transmission of information by such a code is extremely inefficient.

Many of the time code formats are even more inefficient in this respect than required to present the complete time word in that they contain many extra position identifiers, unused index marks, and control bits. For example, the time word and the frame reference mark in the IRIG B format could be transmitted with a minimum of 32 elements. The actual formatuses 100 elements requiring a bandwidth of three times that required to transmit only the frame word.

This statement is based on the supposition that the 32-element code word is distributed evenly over the same 1-second frame and that the element period is approximately 3 times the element period of the 100-element code. Also, that the 32-element code is width coded with the width of the narrowest element and the same percentage of the element period.

However, these inefficiencies in time codes can be justified to a large extent. For time tagging most data, it is desirable that each and every frame of time code contain all the information required to identify time to the period of the element rate of the code without reference to other time frames. The additional information/bandwidth inefficiency is justifiable in a time code format for the following reasons.

a. The additional elements provide additional resolution in the time code format. In the example involving the IRIG B format, the resolution of the 100-element frame is three times that of the 32-element frame.

b. By including extra elements in the frame with the time word, the element rate can be made a "logical" multiple of the frame rate. In the above example, the 32-per-second element rate is not a logical multiple of a 1 pps frame rate. The lowest "logical" element rate for such a code would be 50 pps, providing 50 code elements to transmit the 32-element time frame.

The factors discussed above greatly overshadow information/bandwidth efficiency as yardsticks for determining the worth of a time code format.

If bandwidth were limited, great improvements can be made in generating usable time code formats. For example, a serial-sequential time code format which would provide coded time information in one-tenth second increments at a 10-frame per second rate without the bandwidth requirements of IRIG A is suggested.

The serial portion of this code would have 20 elements with coded time in tenths, units, and tens of seconds. The serial code would also contain four data bits whose binary value on sequential frames would represent sync (Binary 15), unit minutes, tens of minutes, separator (Binary 10), units hours, tens hours, separator (Binary 10), unit days, tens days, and hundreds days. A complete time code including day of year would be delivered for each 10 frames of serial code (one complete code each second).

The elements used in this code would have time dimensions one-half the width of those presently used in IRIG B and would use a 2 kc carrier in the modulated carrier form, thus the same number of enhanced carrier cycles would define a data zero, data one, and position identifier pulse.

This code could be transmitted over a 3 kc bandwidth circuit and would give complete time identification to any asynchronously started test of at least two seconds duration.

A 1-pps pulse rate would be a by-product of the sequential data sync detection. Basic frequencies contained in this code are:

a. Carrier: 2 kc

b. Index Rate: 200 pps

c. Serial Frame Rate: 10 pps

d. Sequential Frame Rate: 1 pps

Time Intervals Encoded

The most logical time intervals to be encoded in time code system with a recycle interval of one year are days, hours, minutes, and seconds. Certain programs of short duration (less than one day) involving reduction of data by computers can operate more efficiently on a time code consisting of an accumulation of seconds for a day.

In certain short duration operations an accumulation of seconds from some specialized event (such a lift-off of a booster) would be desirable. However, a system which provides coding in days, hours, minutes, and seconds provides the most usable time information for a wide range of programs.

Time Codes in a Family of Codes

As stated in the previous section, a basic timing system must provide a "family of codes" with several frame lengths and element readout rates to provide timing information with a resolution commensurate with the highest significant frequency contained in the data to be time tagged. It is desirable that the frame lengths provided be logical subdivisions or multiples of the time intervals encoded in the basic time code format. The one-second frame, the one-minute frame and the one-hour frame are certainly the most logical frame lengths for a basic code system which encodes intervals of days, hours, minutes, and seconds.

Both the IRIG family and the NASA family of codes provide these three frame intervals. As pointed out in the previous section (table 2, page 63), there is a ratio of 60:1 between adjacent codes with these three frame intervals. The addition of the .1 second frame, the 10-second frame, and the 5-minute frame in the IRIG family reduces the the ratio between frames to a maximum of 12 and a minimum of 5 as shown in table 2.

A code with a frame length of 10 minutes rather than the 5-minute frame in the proposed IRIG F format would provide a more constant ratio between the intervals of adjacent codes. Such a reduction would provide ratios of 10 and 6 between the last three codes rather than the ratios of 5 and 12 in the last three IRIG codes.

As stated in the previous section, a family with a nominal ratio of 10:1 between adjacent code intervals provides timing information with a resolution that is either greater than or less than the optimum resolution for a given data frequency by a factor of no more than 3.16:1.

4. Time Word Coding

Two types of coding are acceptable for a family of time codes in which the encoded intervals are days, hours, minutes and seconds. The two types of coding are "binary coded decimal" (BCD) as used in the NASA and IRIG families of codes and "grouped binary" as used in the AMR, Eglin, and Edwards codes.

The advantages of BCD Coding are:

a. Most easily read by humans. Grouped binary coding up to 59 seconds and 59 minutes can be read by a human with adequate training. It would be very difficult to read a single binary word for day of year.

b. Most easily adapted to drive a decimal visual display.

c. Suited for a generator system which produces output output rates in decimal multiples and subdivisions of 1 second.

The advantages of grouped binary coding are:

a. Fewer code elements on bits are required to encode the time message, providing a somewhat more efficient code from an information/bandwidth point of view.

b. Can be converted to seconds in a computer somewhat more more efficiently than BCD.

Binary coded decimal is the most desirable code for a wide variety of programs especially in a time code system in which day of year is encoded.

Order of Code Word Readout

Time code words can be readout with the least significant elements first or with the most significant elements first.

The advantages of an LSD to MSD code readout are:

a. It is easier to synchronize a terminal timing unit, a time code decoder, or a time code translator which contains an accumulator since direction of carry counts in such an accumulator is from LSD to MSD.

b. In records which are analyzed by humans, the code elements which undergo the greatest change from frame to frame are read out first near the reference mark.

The main advantage of an MSD to LSD readout is that it permits the visual observer to see the number displayed in the normal manner, i.e., most significant digit to the left and least significant digit to the right as viewed on the record.

It is felt that the advantages of a least significant digit to most significant digit code word readout order over weigh the disadvantages mentioned above.

5. Form of Coding

Pulse width coding of time code formats is the most suitable form of coding in a set of codes designed for general use for the following reasons:

a. Pulse width coding is suitable for recording on magnetic tape.

When recorded on direct record electronics in the amplitude modulated carrier form, it can be played back and decoded using reliable cycle counting techniques. It can be played back and decoded at tape speeds which are higher or lower than the record speed.

Pulse width coding can be recorded on magnetic tape using FM techniques in either the modulated carrier or dc level shift form.

b. Pulse width coding in the dc level shift form is optimum for recording time information on film using neon bulbs.

c. Pulse width coding in the dc level shift form is optimum for recording on strip chart recorders, either on a normal data channel or on on-off type event channels.

d. Pulse width coding in either the dc level shift form or the modulated carrier form is optimum for recording on oscillographs.

Width of Coded Elements

Both the IRIG and the NASA families of codes use width coding.

The NASA code elements are coded using two different widths: an element with a width of 20% of the period of the element rate represents a binary "zero"; an element with a width of 60% of the element rate period represents a "one," a position identifier, and a reference mark, depending on position in the frame and relationship with other elements. Five sequential "ones" identify a reference mark. Four sequential "ones" can occur in other parts of the data frame -- a position identifier followed by a decimal digit coded "7."

The IRIG codes utilize three different element widths in the code word: an element with a width of 20% of the element period represents a "zero," 50% represents a "one", and 80% represents a position identifier and reference mark. Position identifiers and the reference mark are more easily identified visually in the IRIG codes than they are in the NASA codes because of the third width.

Comparable codes in the NASA and IRIG families contain the same frequency components. The width of the narrowest pulse in a code will determine the bandwidth required to handle the code (assuming a modulated carrier is used to provide dc response capabilities).

Most of the significant energy components of a rectangular pulse will be contained in a band of frequencies (in cycles per second) from 0 to $\frac{1}{\text{pulse width (seconds)}}$ (the frequency of the first zero in the spectral energy distribution envelope).

For example, both the NASA 36-bit code and IRIG Format B encode a zero with an element which is 2 ms wide in a 1 second time frame. The frequency of the first spectral zero in both codes is then $\frac{1}{.002}$ = 500 cycles/second.

A time code with only two element widths can be generated which requires less bandwidth than a code using three element widths, since a wider "zero" element can be used and maintain the ability to distinguish between a "one" and a "zero." For example, a 100 pps code with 3.3 ms and 6.7 ms element widths would provide a ratio of 2:1 in element widths and have the first spectral zero at $\frac{1}{.00333}$ = 300 cycles/second.

A code with element widths of 33 and 67% are not practical. Widths of 30% and 70% would be chosen to provide elements which were decimally related.

If a family of time codes is built using a constant number of code elements and with the narrowest pulse a constant fraction of the pulse-to-pulse spacing (and therefore a constant fraction of the time code frame interval), the significant energy components of the codes (out to first zero in spectrum envelope) will be contained in a bandwidth equal to the frame rate (in frames per second) multiplied by the reciprocal of the fraction of the frame interval represented by the narrowest pulse code. For example, for a narrowest pulse that is always 1/500 of the frome interval, then the significant energy components will fall in a bandwidth equal to 500 x frame rate and, when these pulses are used to amplitude modulate a carrier frequency, double sideband frequencies of ±0 to 500 x frame rate will result.

6. Reference Mark Coding

Reference marks in time codes are designed to have a combination of code bits that are never present in the remainder of the coded time frame.

The extent to which a reference mark code of N number of bits differs from any possible combination of the same number of data bits determines the "uniqueness" of the code.

A large degree of "uniqueness" can be used in two ways. The test which is used to detect the reference mark can be relaxed, thus allowing a correct identification of the reference mark even though the reference mark code is not correctly reproduced, and at the same time an incorrect reproduction of the time data bits will not create a "false" reference mark code.

The reference mark code has additional identifying qualifications in that it occurs (with proper reproducing equipment) at precise time intervals, is preceded by a specific number of index markers, and is preceded by a specific number of position identifiers. A very elaborate test for detection of the reference mark can be built in if <u>all</u> of the redundant information contained in the time code is required as a condition of the reference mark test.

The reference point in the NASA BCD time codes is defined as the leading edge of the pulse following a sequence of five "wide" pulses where a wide pulse is 60% of the index interval as opposed to "narrow" pulses that are 20% of the index interval.

Five successive "wide" pulses are required for a unique marker in that the coding of the individual decades of time information can contain up to four successive "wide" pulses, e.g., a "wide" position identifier followed by a code value of 7 (bits 1, 2, and 4 are "wide" pulses).

The reference point in the IRIG time codes is defined as the leading edge of the second of two successive position identifier pulses. Only two successive position identifier pulses are required for a unique marker because the IRIG codes use three values of pulse widths with the widest (80% of index interval) reserved for position identifier and reference marker use.

One fundamental difference between the reference mark coding used in NASA codes and that used in IRIG codes is the placement of the defined "on time" point after complete presentation of the reference mark bit pattern in the case of NASA codes and the placement of the defined "on time" point within the reference mark bit pattern in the IRIG codes. Automatic circuitry used to decode the NASA time code can complete its reference mark qualification tests in advance of the on time point. Circuitry used to decode IRIG level shift code formats must utilize the position identifier or index marker count, based on a prior correctly read frame, to qualify the leading edge of the next pulse following the P_0 position identifier as the "on time" point. This qualification is then verified by the identification of this pulse as having a width equal to 80% of the index interval. When verified this "on time" definition can then be the basis of a pulse count that will allow "prediction" of the next on time pulse.

The IRIG code, with its three pulse widths which allow unique position identifier pulses, is easier to interpret than the two-width NASA code.

7. Summary

The IRIG and NASA families of time code formats possess most of the characteristics discussed above. Both of these code systems have the following characteristics:

a. Recycle interval of one year.

b. Encoded intervals of days, hours, minutes, and seconds.

c. BCD coding with LSD to MSD code word readout order.

d. Width coding.

The IRIG family of codes provides more complete coverage of the data spectrum with the addition of the .1 second frame, the 10-second frame and the proposed 5-minute frame. Of course, these frames could be added to the NASA family of codes.

The IRIG family of codes is more easily read since it employs elements with three widths rather than two widths.

The IRIG family of codes provides better frame utilization than the NASA family in that two decades of information are presented between position identifiers rather than only one decade. Thus, the time word is presented in a smaller portion of the frame providing more time for processing before and following frame arrives.

The IRIG family contains the optional straight binary accumulation of recycling each day in the fast codes which is suitable for short duration programs which involve automatic data reduction.

C. PRELIMINARY ANALYSIS OF TIMING ACCURACY

1. General

This analysis is concerned with factors affecting timing accuracy from the reference in the time code generator to recorded data which is time tagged with the timing signal. The analysis does not cover timing inaccuracies caused by time code generator synchronization or by the accuracy and stability of frequency standards used to drive the time generators.

The analysis, then, is concerned primarily with the delays inherent in a typical timing system; both the magnitude and constancy of these delays.

2. Time Generator Delays

Timing accuracy considerations involving the typical time code generator are primarily the coherency of the various outputs with respect to the reference pulse (usually the 1 pps output).

Time displacements have been measured between various outputs and rates from a typical time code generator using non-clocked outputs. This generator has a one megacycle input frequency and uses flip-flops with a maximum operating frequency of 1 mc in the pulse rate divider to divide between 1 megacycle and 10 kilocycles. Flip-flops with a maximum operating frequency of 200 kc are used in the balance of the pulse rate divider (10 kc to 1 pps) and in the accumulator (1 pps to 1 pulse per 200 days).

The time displacements relative to the 1 pps signal are:

1 pp 200 days	late by 2 microseconds
10 kpps	early by 1.1 microseconds
Binary 1pp2^{16}s	late by 1.8 microseconds

Modulated 1 kc carrier (IRIG B format) axis crossing time jitter -- 2 microseconds.

3. Transmission Delays on Wire Transmission Circuits

These delays are dependent upon the type of circuit and cable used -- open wire toll cable, carrier equipment, etc. A typical delay for Quadded toll cable with 19 gauge conductors is 10 microseconds per mile (approximately 80% greater than for open wire lines).

Wire transmission delays should be measured whenever possible and recorded over a sufficient time span to disclose any significant short- and long-term variations.

4. Time Delays in Timing Terminal Equipment.

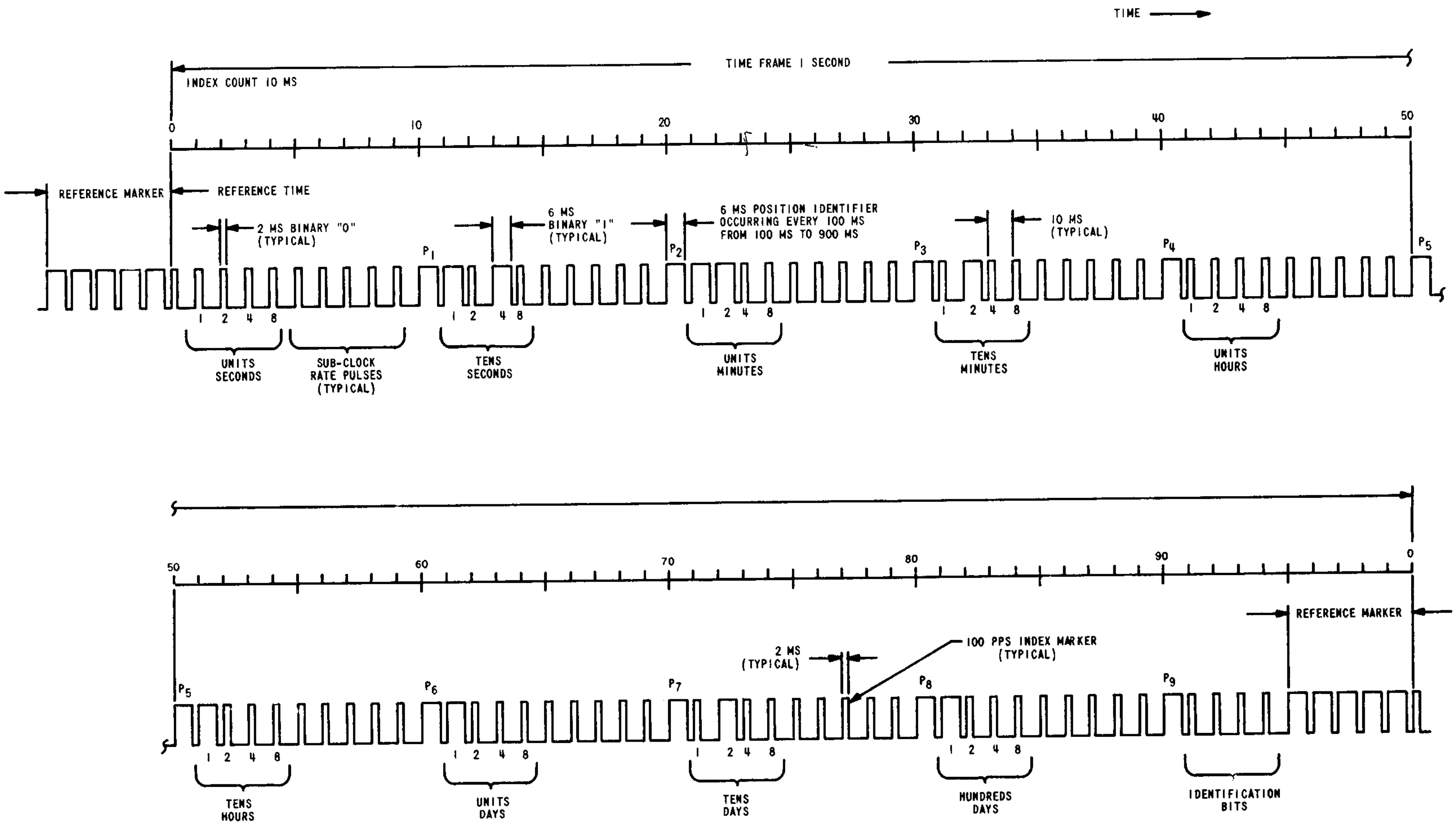
Delays have been measured for terminal equipment which decodes serially coded time information and makes this data available in a parallel form.

For equipment which uses envelope detection, typical delays are 12 microseconds when using IRIG A (10 kc carrier) and 100 microseconds when using IRIG B (1 kc carrier).

For equipment which uses cycle counting, typical delays are 25 microseconds when using IRIG B (1 kc carrier).

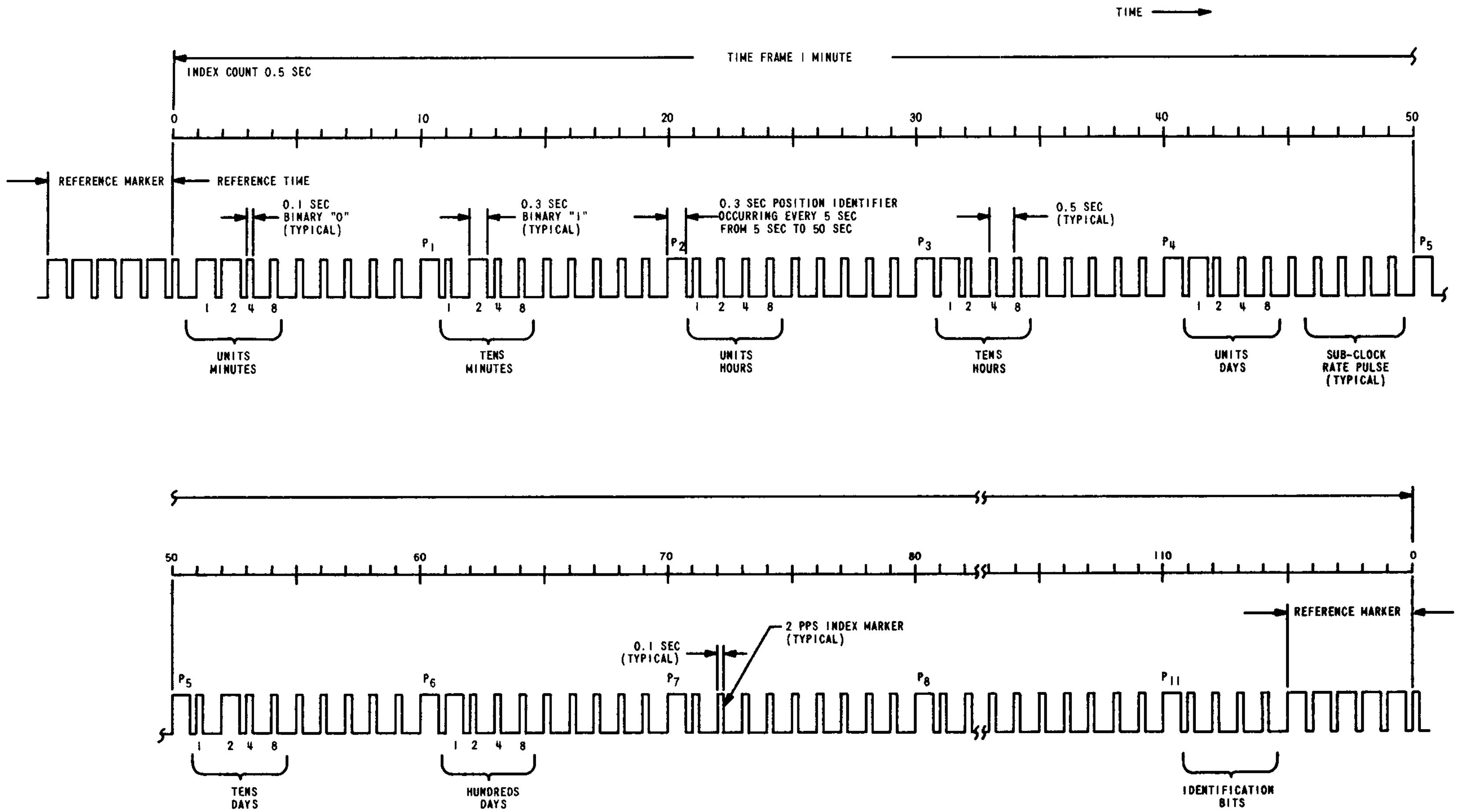
Amplified versions of the input code are available with zero axis time displacements of less than .1 microsecond.

APPENDIX I
Time Code Formats



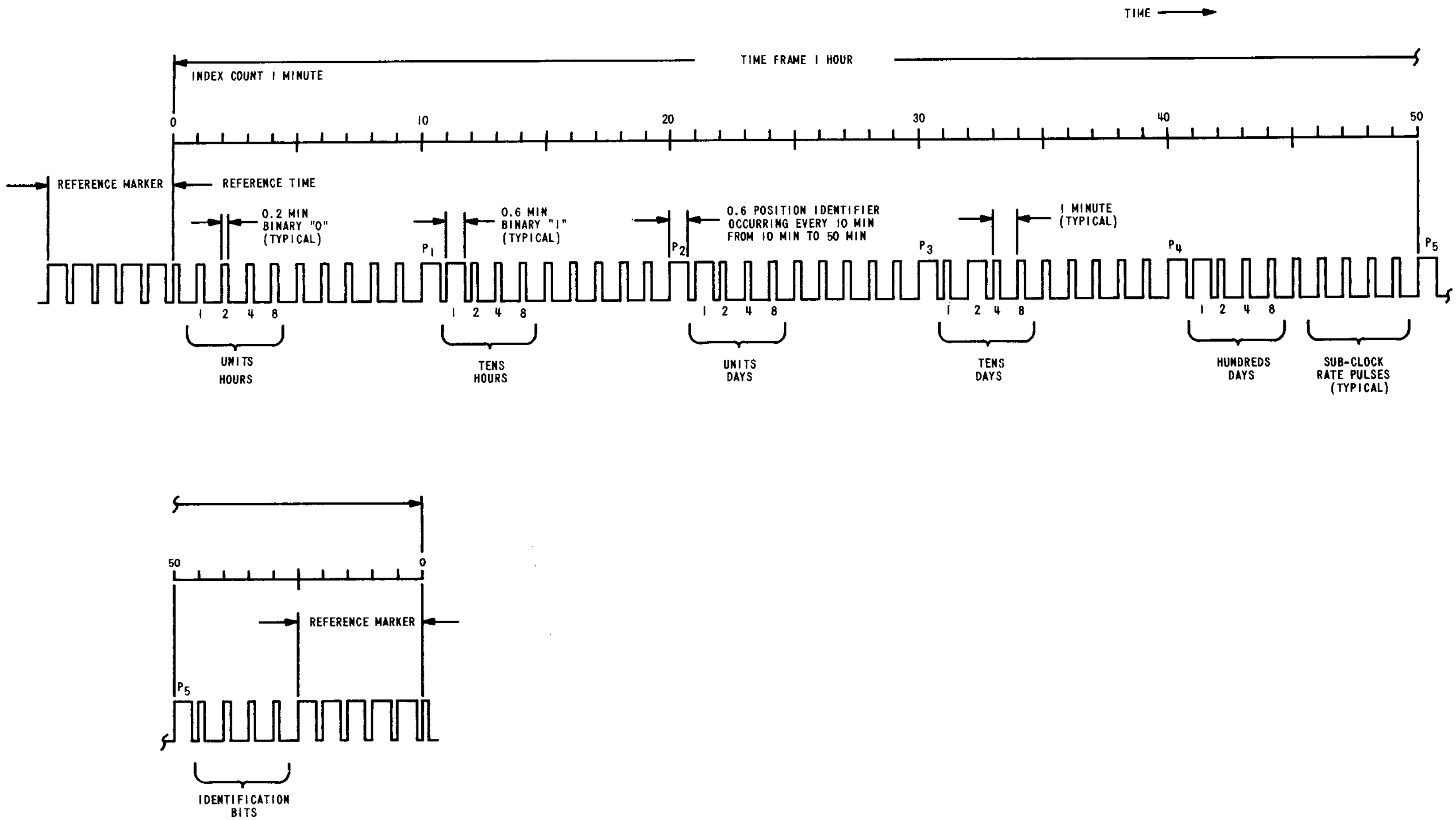
TIME AT REFERENCE: 121 DAYS, 10 HR., 23 MIN., 50 SEC

TITLE NASA 36-BIT BCD TIME CODE 100 PPS	CHECKED	DRAWN BY OLDEWAGE	DATE 27JAN65	PROJ
	PUBLICATIONS		5 MAY 65	SHEET 1.0 OF
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA	PROJECT ENGR		6 MAY 65	DWG. NO. A35100
	GROUP ENGR			
	CHIEF ENGR			



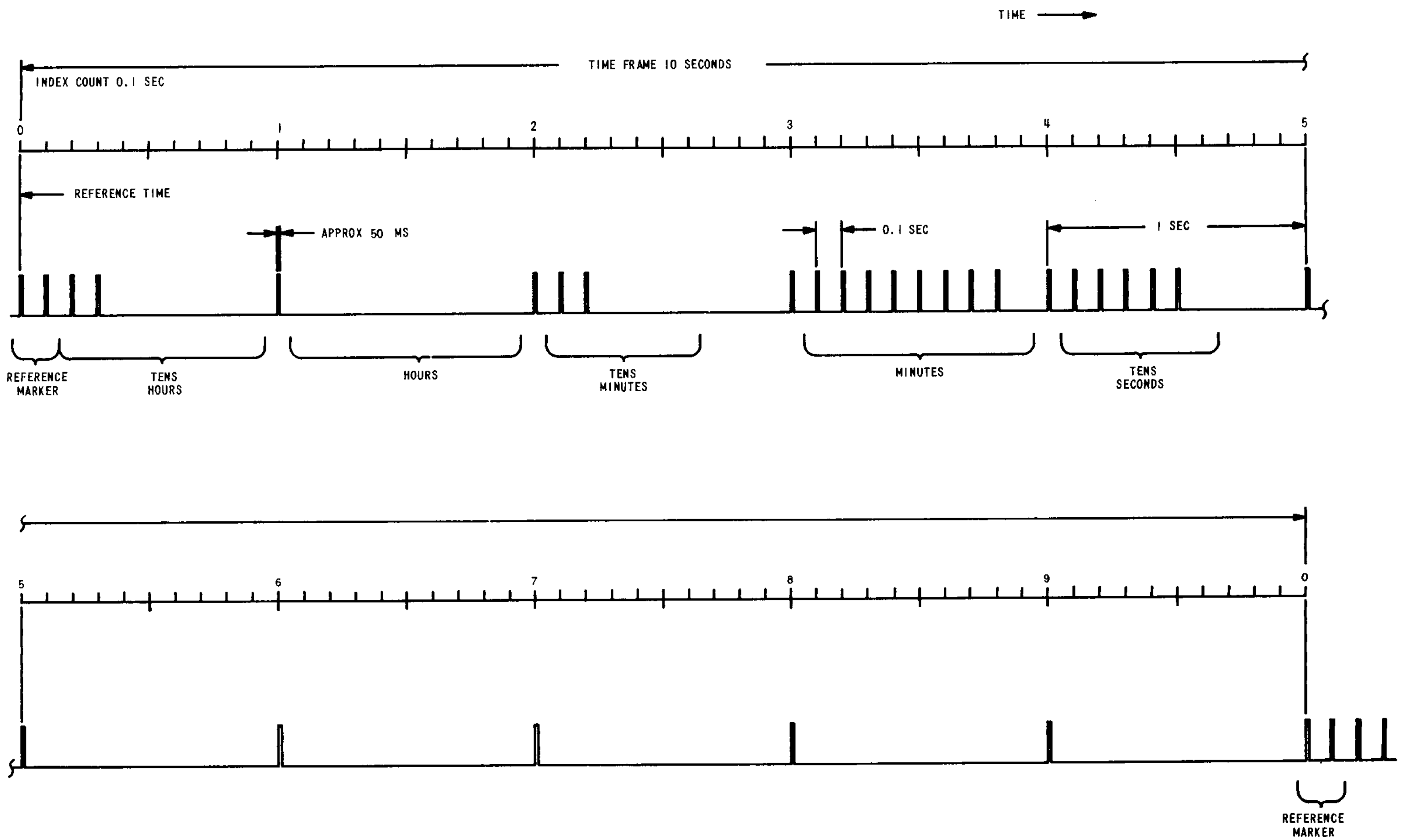
TIME AT REFERENCE: 121 DAYS, 10 HOURS, 23 MINUTES

TITLE: NASA 28-BIT BCD TIME CODE 2 PPS	DRAWN BY: OLDEWAGE	DATE: 27JAN65	PROJ
		5 MAY 65	SHEET 2.0 OF
		6 MAY 65	DWG. NO. A35100
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA			



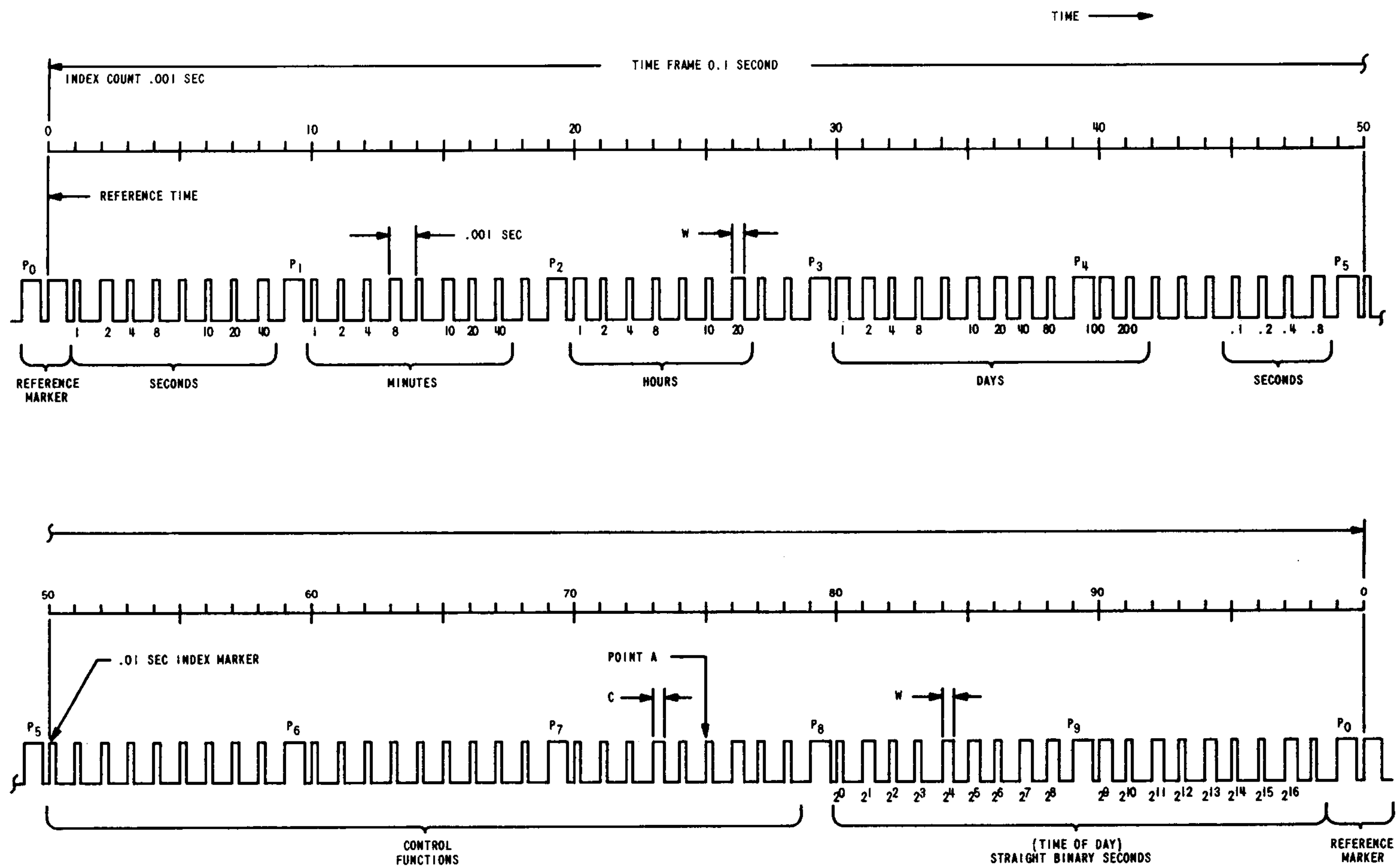
TIME AT REFERENCE: 121 DAYS, 10 HOURS

TITLE			
NASA 20-BIT BCD TIME CODE 1 PPM	DRAWN BY OLDEWAGE	DATE 27JAN65	PROJ
	PUBLICATIONS	5 MAY 65	SHEET 3.0 OF
	PROJECT ENGR	6 MAY 65	DWG. NO. A35100
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA	CHIEF ENGR		



TIME AT REFERENCE: 20HR ., 28MIN ., 50SEC

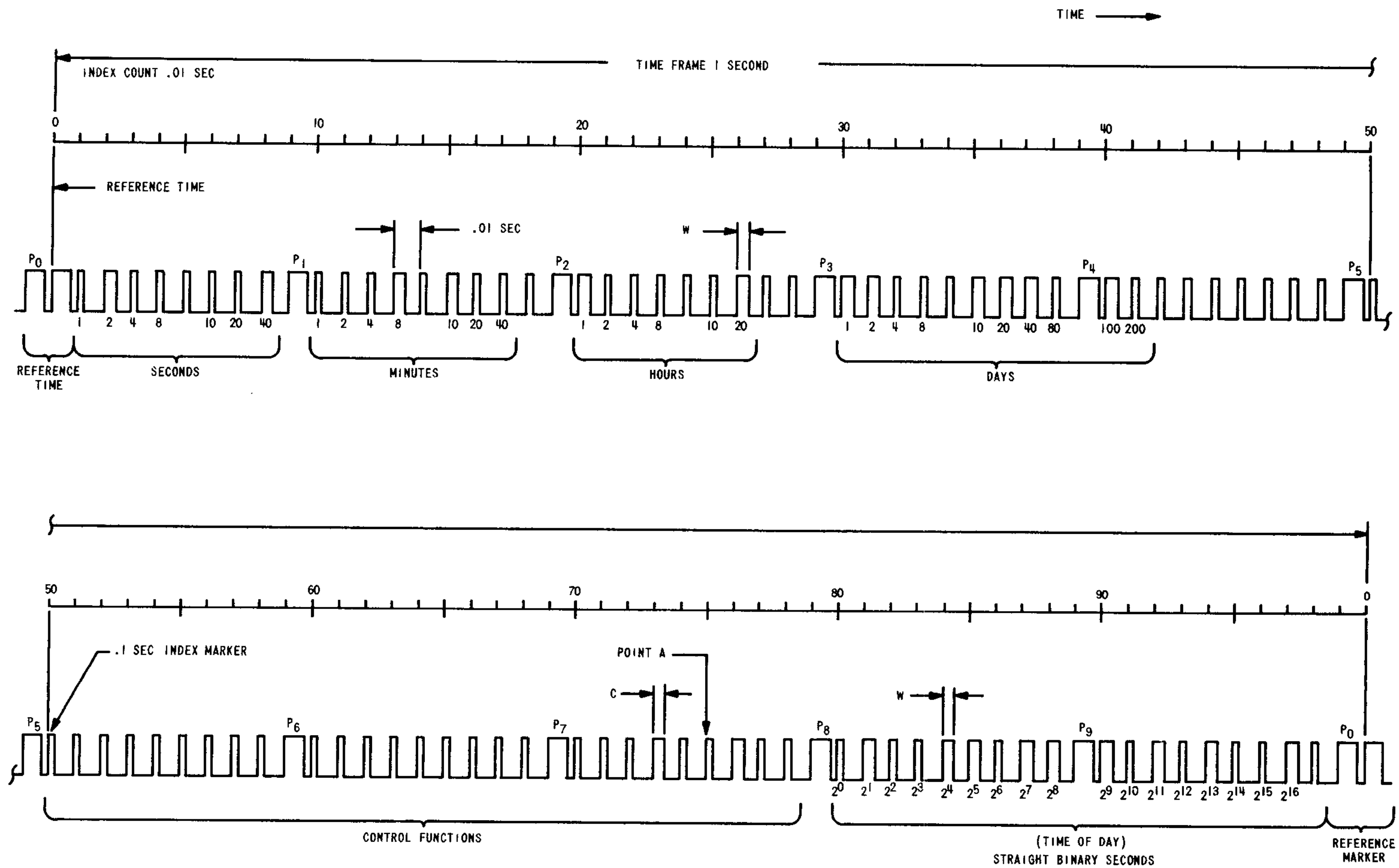
TITLE NASA SERIAL DECIMAL TIME CODE	CHECKED	DRAWN BY O. DEWAGE	DATE 27JAN65	PROJ
	ENGINEER	PUBLICATIONS		SHEET 4.0 OF
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA	PROJECT ENGR		MAY 65	DWG. NO. A35100
	GROUP ENGR			
	CHIEF ENGR			



P=POSITION IDENTIFIER, 0.8MS DURATION
W=WEIGHTED CODE DIGIT, 0.5MS DURATION
C=CONTROL ELEMENT (EXAMPLE) 0.5MS DURATION
DURATION OF INDEX MARKERS = 0.2MS

TIME AT POINT A: 21:18:42+.8+.07+.005
= 21 HR., 18 MIN., 42.875 SEC ON DAY 173

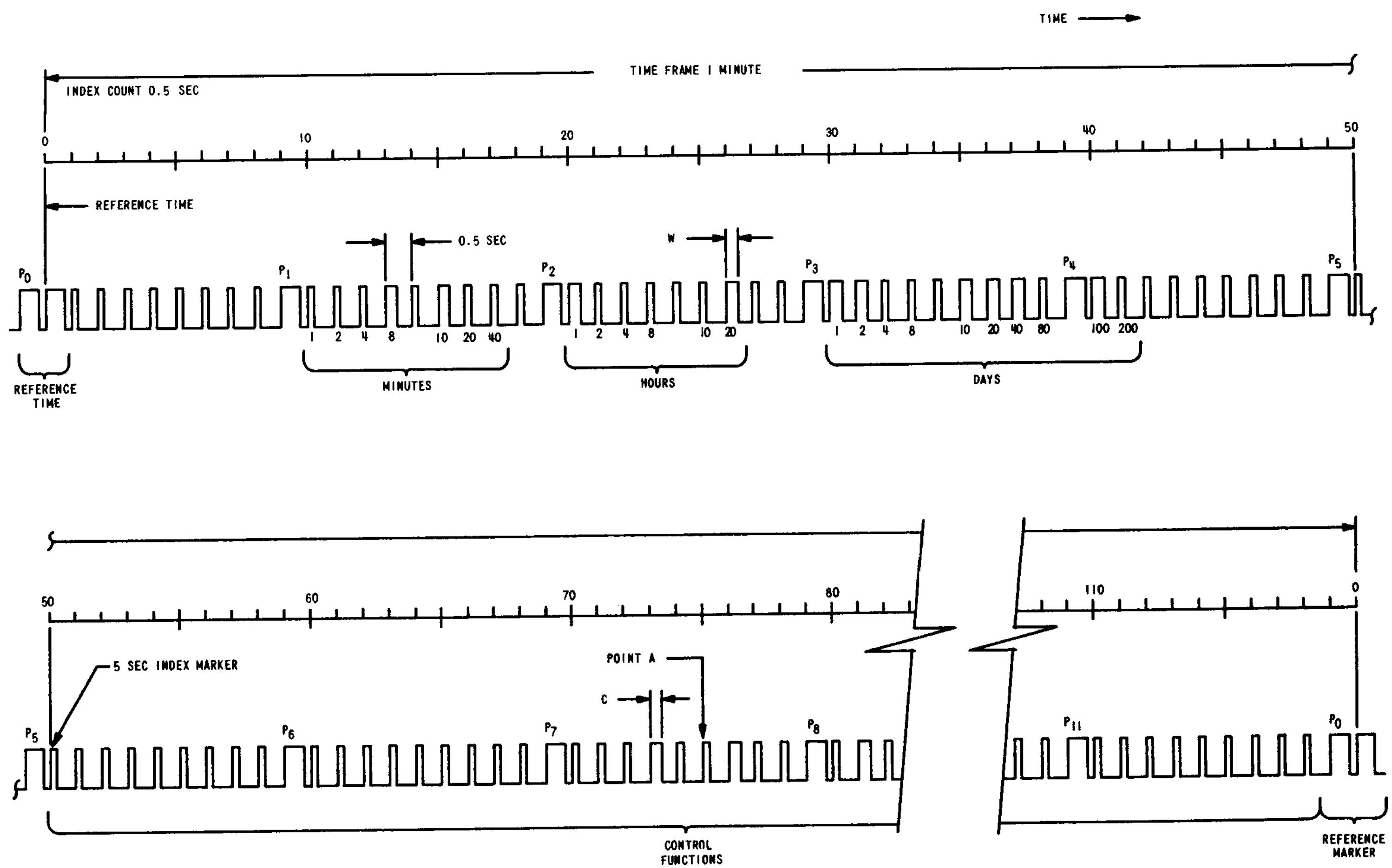
TITLE	CHECKED	DRAWN BY	DATE	PROJ
1000PPS CODE IRIG STANDARD FORMAT A		OLDEWAGE	27JAN65	SHEET 5.0 OF
	ENGINEER	PUBLICATIONS	6 MAY 65	
	PROJECT ENGR		6 MAY 65	DWG. NO. A35100
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA	GROUP ENGR / CHIEF ENGR			



P = POSITION IDENTIFIER, 8MS DURATION
W = WEIGHTED CODE DIGIT, 5MS DURATION
C = CONTROL ELEMENT (EXAMPLE), 5MS DURATION
DURATION OF INDEX MARKERS, 2MS

TIME AT POINT A = 21:18:42 +.7 +.05
= 21 HR., 18 MIN., 42.75 SEC. ON DAY 173

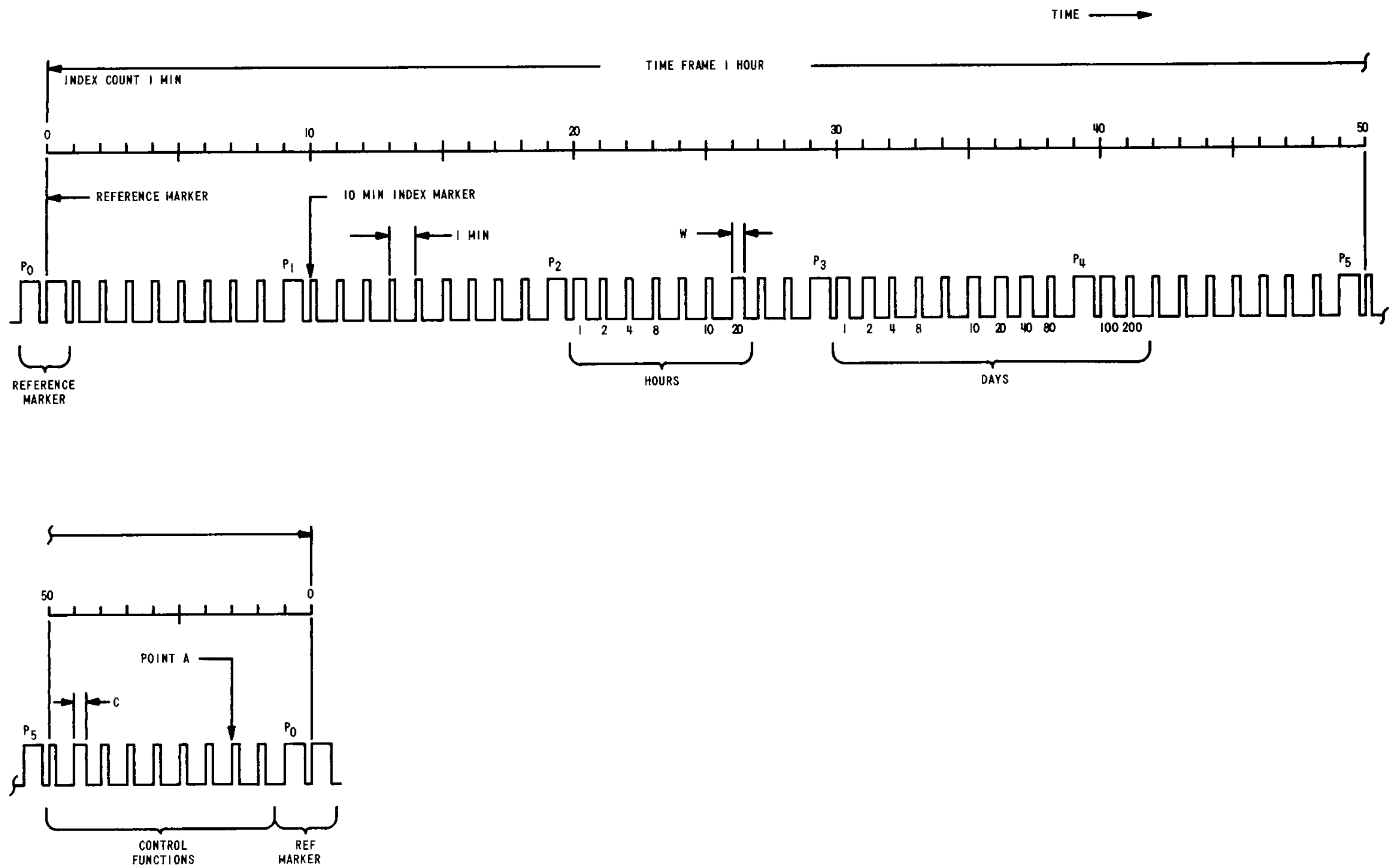
TITLE	CHECKED	DRAWN BY CLDEWAGE	DATE 27JAN65	PROJ
100PPS CODE IRIG STANDARD FORMAT B	ENGINEER	PUBLICATIONS	6 MAY 65	SHEET OF 6.0
	PROJECT ENGR		10 MAY 65	
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA	GROUP ENGR			DWG. NO. A35!00
	CHIEF ENGR			



TIME AT POINT A = 21:18 + 37.5 SEC
= 21 HR., 18 MIN., 37.5 SEC ON DAY 173

P=POSITION IDENTIFIER, 0.4SEC DURATION
W=WEIGHTED CODE DIGIT, 0.25SEC DURATION
C=CONTROL ELEMENT (EXAMPLE), 0.25SEC DURATION
DURATION OF INDEX MARKERS = 0.1SEC

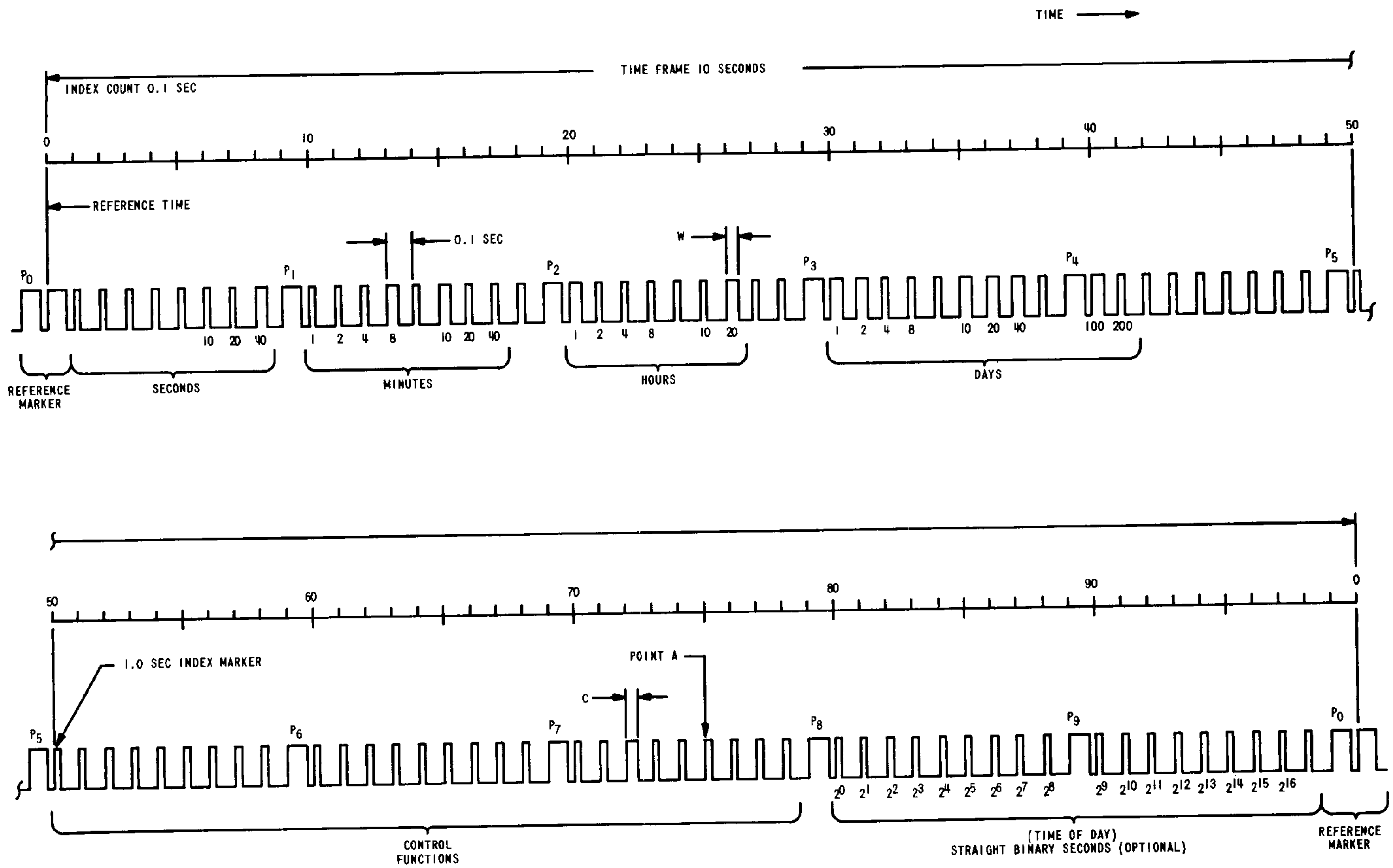
TITLE 2PPS CODE IRIG STANDARD FORMAT C	CHECKED	DRAWN BY OLDEHAGE	DATE 27JAN65	PROJ
	ENGINEER	PUBLICATIONS	4 MAY 65	SHEET 7.0 OF
	PROJECT ENGR		6 MAY 65	
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA	GROUP ENGR			DWG. NO. A35100
	CHIEF ENGR			



P=POSITION IDENTIFIER, 48SEC DURATION
W=WEIGHTED CODE DIGIT, 30SEC DURATION
C=CONTROL ELEMENT (EXAMPLE), 30SEC DURATION
DURATION OF INDEX MARKERS = 12SEC

TIME AT POINT A = 21HR, 57MIN, ON DAY 173

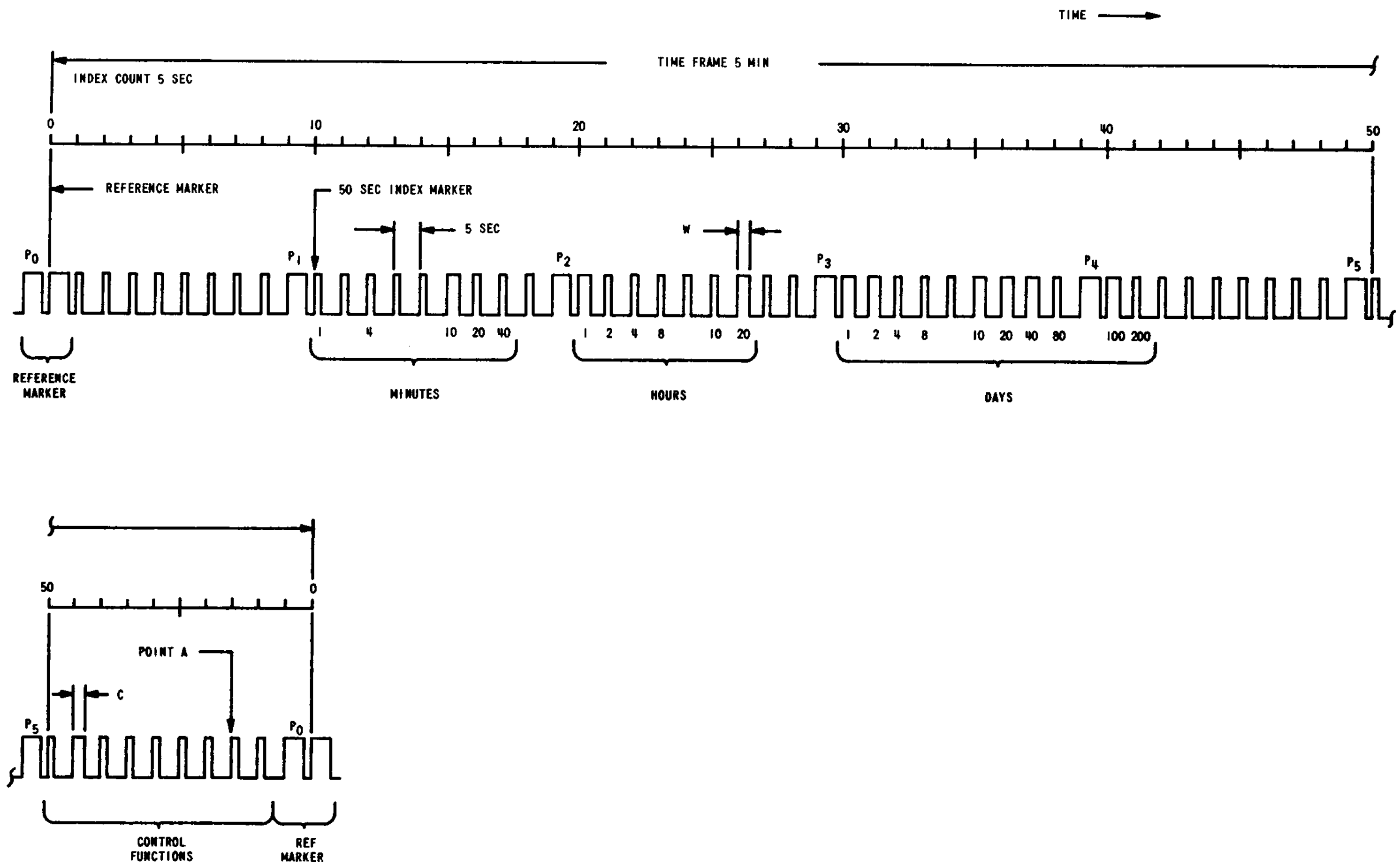
TITLE	CHECKED	DRAWN BY	DATE	PROJ	
IPPM CODE IRIG STANDARD FORMAT D		OLDEWAGE	27JAN65		
	APPROVED	PUBLICATIONS	6 MAY 65	SHEET	8.0
	PROJECT ENGR		6 MAY 65	OF	
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA	GROUP ENGR			DWG. NO.	A35100
	CHIEF ENGR				



P=POSITION IDENTIFIERS, 80MS DURATION
W=WEIGHTED CODE DIGIT, 50MS DURATION
C=CONTROL ELEMENT (EXAMPLE), 50MS DURATION
DURATION OF INDEX MARKERS=20MS

TIME AT POINT A = 21:18:40+7.5
= 21 HR., 18 MIN., 47.5 SEC ON DAY 173

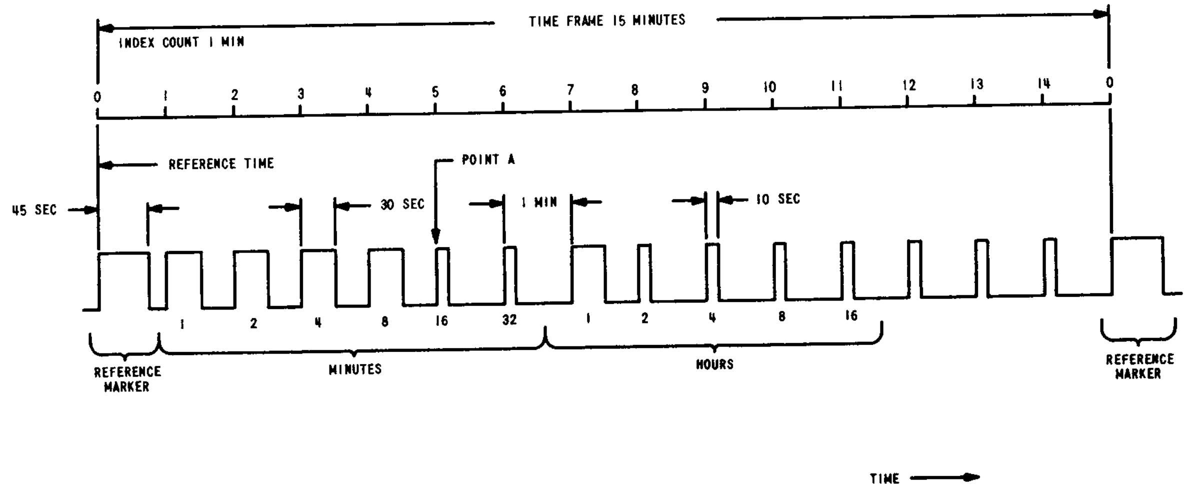
TITLE: 10PPS CODE IRIG STANDARD FORMAT E	CHECKED / DRAWN BY: OLDIVAGE	DATE: 27JAN65	PROJ
	PUBLICATIONS	6 MAY 65	SHEET 9.0 OF
	PROJECT ENGR	6 MAY 65	
	GROUP ENGR		DWG NO A35100
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA	CHIEF ENGR		



P=POSITION IDENTIFIER, 4 SEC DURATION
W=WEIGHTED CODE DIGIT, 2.5 SEC DURATION
C=CONTROL ELEMENT (EXAMPLE), 30 SEC DURATION
DURATION OF INDEX MARKERS = 1 SEC

TIME AT POINT A = 21 HR, 14 MIN, 45 SEC
ON DAY 173

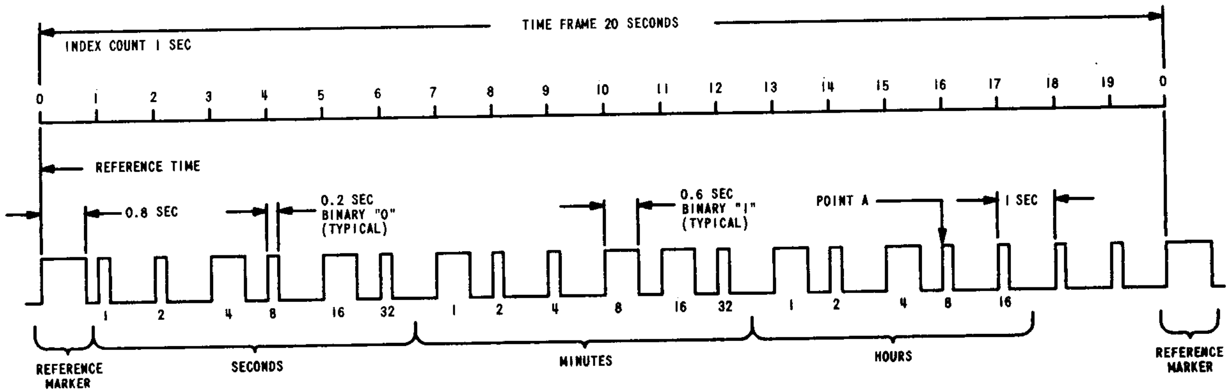
TITLE: IPP 5 SEC IRIG STANDARD FORMAT F	DRAWN BY: OLDEWAGE	27JAN65	PROJ	
		6 MAY 65	SHEET OF	10.0
		6 MAY 65		
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA			DWG. NO.	A35100



TIME AT POINT A = 1 HR., 20 MIN

FORMAT A-1 LEVEL SHIFT
FORMAT A-2 MODULATED CARRIER

TITLE AMR A-1 & A-2 TIME CODES 1 PPM	CHECKED	DRAWN BY OLDEWAGE	DATE 27JAN65	PROJ
	ENGINEER	PUBLICATIONS	6 MAY 65	SHEET OF 11.0
	PROJECT ENGR		6 MAY 65	DWG NO. A35100
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA	GROUP ENGR			
	CHIEF ENGR			

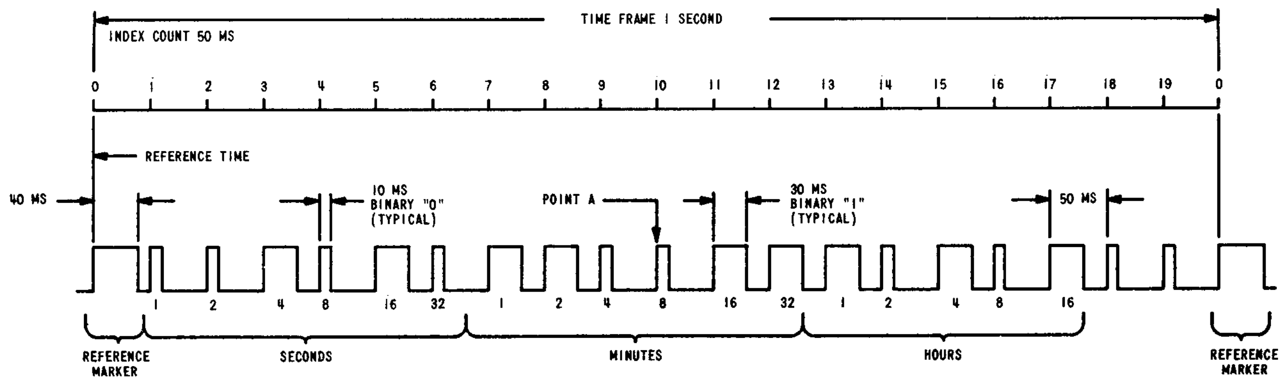


TIME →

TIME AT POINT A = 5 HR., 25 MIN., 36 SEC.

FORMAT B1 LEVEL SHIFT
FORMAT B2 MODULATED CARRIER

TITLE AMR B1 & B2 TIME CODES 1 PPS	CHECKED / DRAWN BY OLDEWAGE	DATE 27JAN65	PROJ
	ENGINEER / PUBLICATIONS	6 MAY 65	SHEET OF 12.0
	PROJECT ENGR	6 MAY 65	
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA	GROUP ENGR / CHIEF ENGR		DWG. NO. A35100

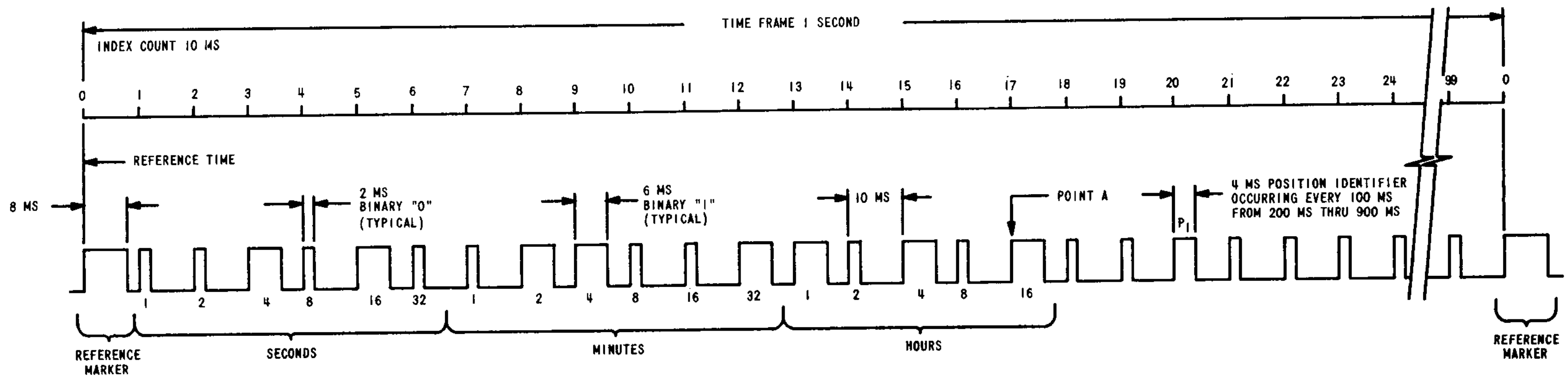


TIME →

TIME AT POINT A = 21 HR., 51 MIN., 20.5 SEC

FORMAT C1 LEVEL SHIFT
FORMAT C2 MODULATED CARRIER

TITLE: AMR C1 & C2 TIME CODES 20 PPS	CHECKED / DRAWN BY: OLDEWAGE	DATE: 27JAN65	PROJ
	ENGINEER / PUBLICATIONS	6 MAY 65	SHEET OF 13.0
	PROJECT ENGR	6 MAY 65	
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA	GROUP ENGR / CHIEF ENGR		DWG. NO. A35100



TIME →

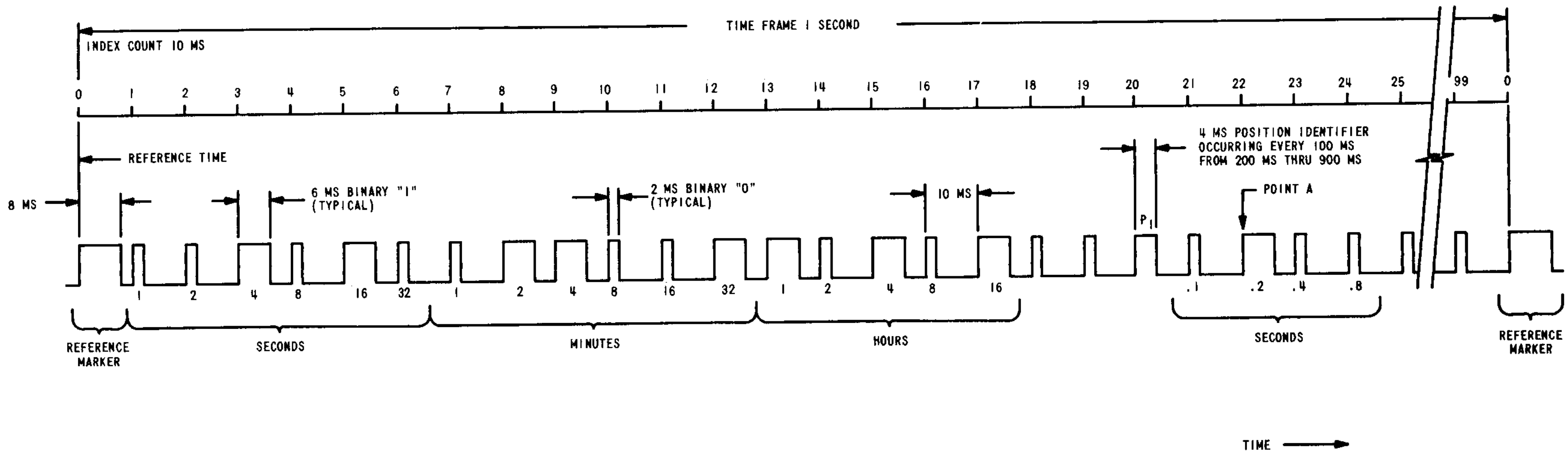
TIME AT POINT A = 21 HR., 38 MIN., 20.17 SEC

FORMAT D1 LEVEL SHIFT
FORMAT D5 MODULATED CARRIER

TITLE
AMR D1 & D5 TIME CODES
100 PPS

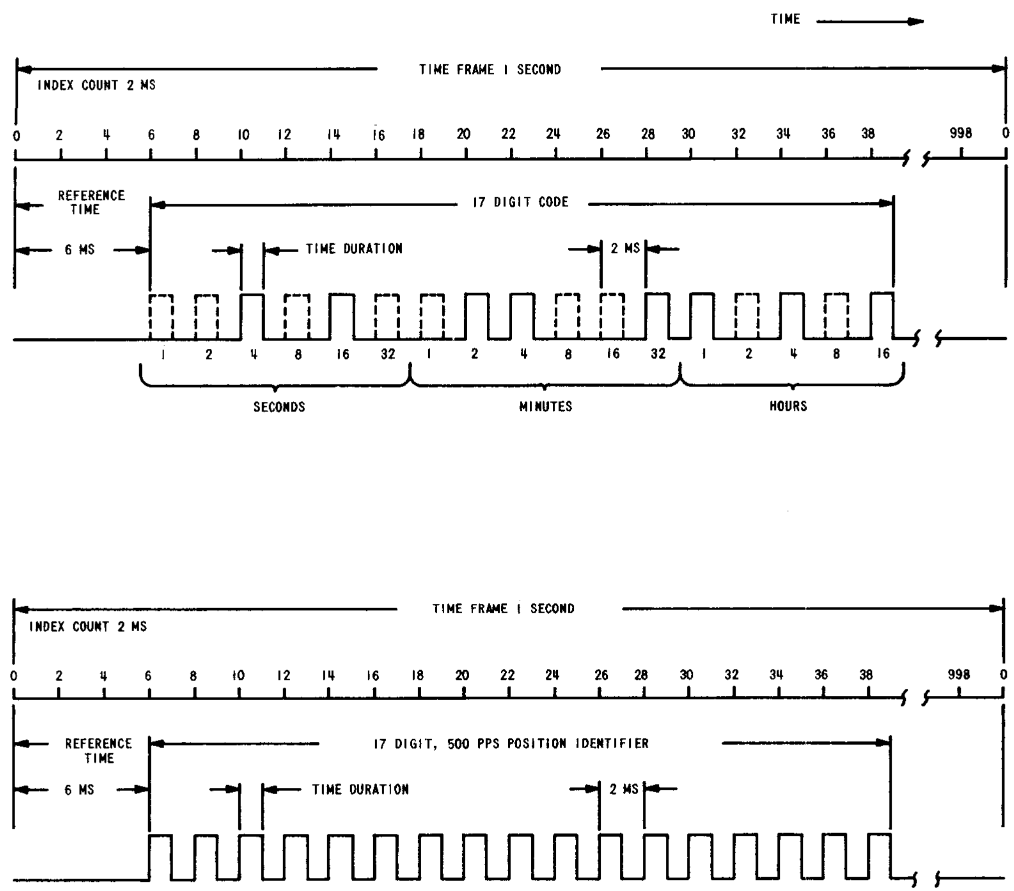
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA
SANTA ANA

CHECKED	DRAWN BY J.L.DEWAGE	DATE 27JAN65	PROJ
ENGINEER	PUBLICATIONS	6 MAY 65	SHEET OF 14.0
PROJECT ENGR		6 MAY 65	
GROUP ENGR			DWG. NO. A35100
CHIEF ENGR			



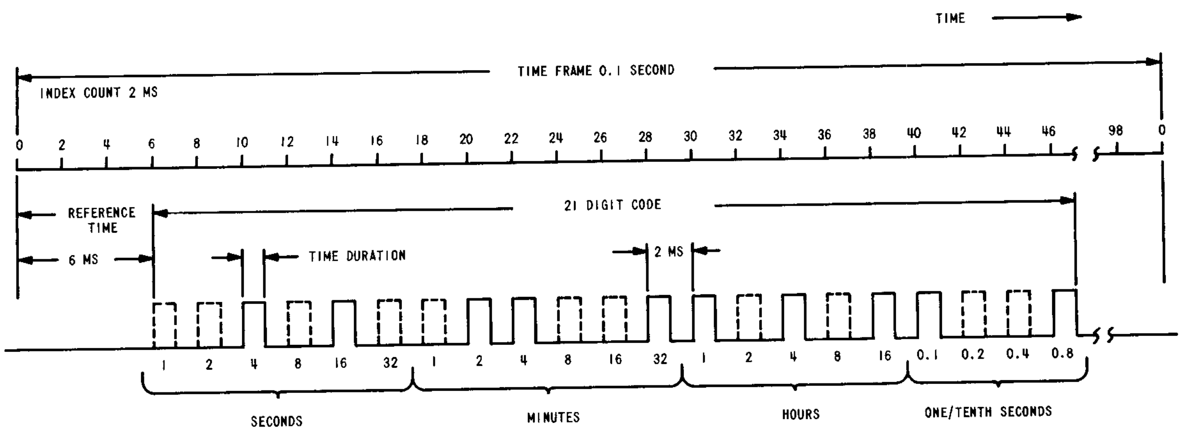
TIME AT POINT A = 21 HR., 38 MIN., 20.22 SEC

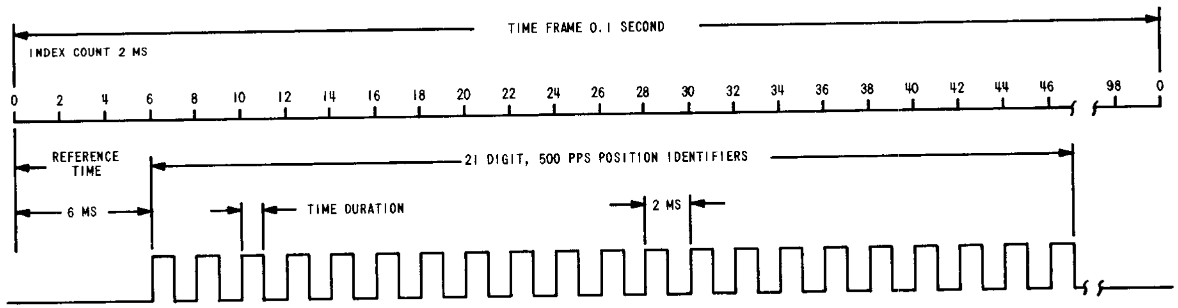
TITLE AMR D2 & D6 TIME CODE 100 PPS	CHECKED / DRAWN BY OLDEWAGE	DATE 27JAN65	PROJ
	ENGINEER / PUBLICATIONS	6 MAY 65	SHEET OF 15.0
	PROJECT ENGR	6 MAY 65	
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA	GROUP ENGR		DWG. NO. A35100
	CHIEF ENGR		



TIME AT REFERENCE: 21 HOURS, 38 MINUTES, 20 SECONDS

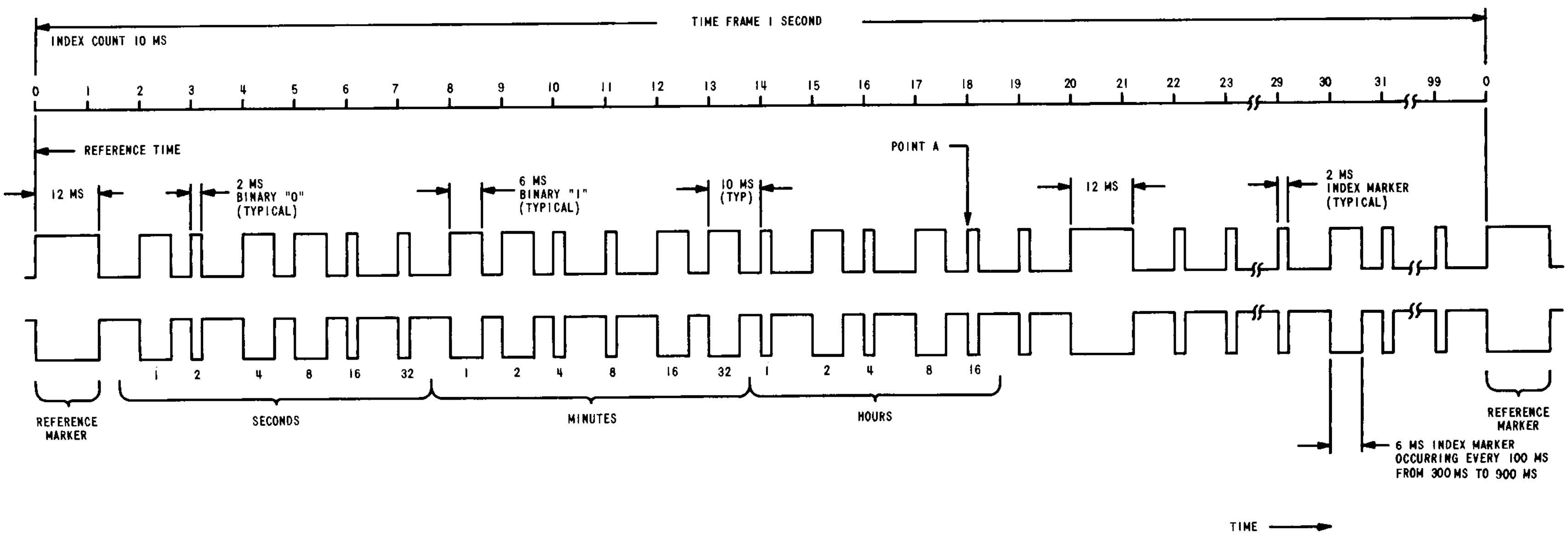
TITLE AMR E1 AND E2 17 BIT POSITION IDENTIFIERS 500 PPS	DRAWN BY DLDEWAGE	DATE 15APR65	PROJ
		6 MAY 65	SHEET 16.0 OF
		6 MAY 65	DWG. NO. A35100
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA	CHIEF ENGR		





TIME AT REFERENCE: 21 HOURS, 38 MINUTES, 20.9 SECONDS

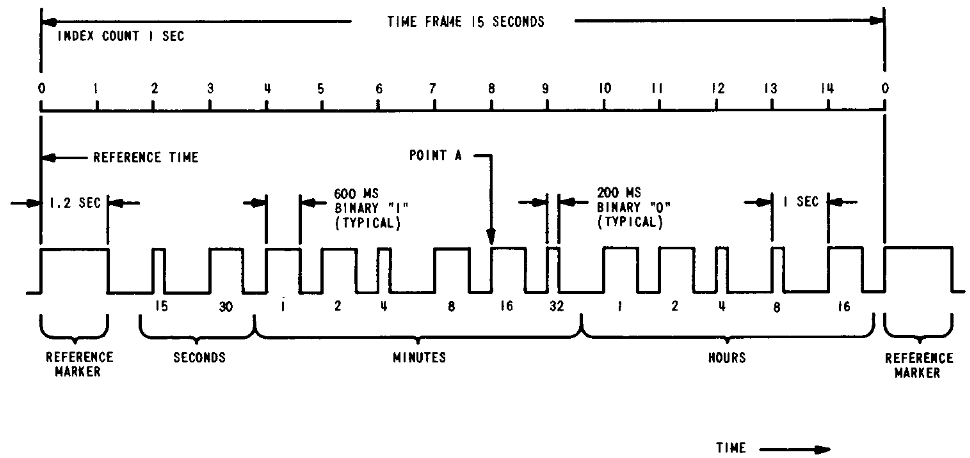
TITLE	CHECKED	DRAWN BY	DATE	PROJ
AMR E3 AND E4 21 BIT TIME CODE 500 PPS		OLDEWAGE	15APR65	SHEET OF 17.0
	ENGINEER	PUBLICATIONS	6 MAY 65	
	PROJECT ENGR		6 May 65	DWG. NO.
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA	GROUP ENGR / CHIEF ENGR			A35100



MODULATED CARRIER ENVELOPE CARRIER 1000 CPS

TIME AT POINT A = 10 HR., 51 MIN., 13.18 SEC

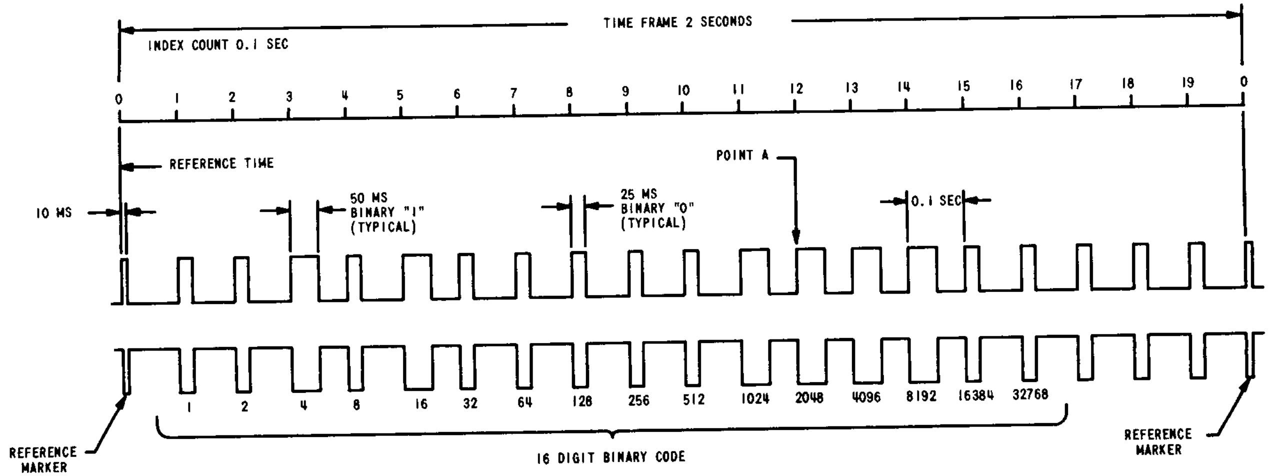
TITLE APGC EGLIN TIME CODE SIGNAL #4 100 PPS	CHECKED	DRAWN BY OLDEWAGE	DATE 1FEB65	PROJ
	ENGINEER	PUBLICATIONS	6 MAY 65	SHEET 18.0 OF
	PROJECT ENGR / GROUP ENGR		6 MAY 65	DWG NO. A35100
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA	CHIEF ENGR			



TIME AT POINT A = 19 HR., 27 MIN., 38 SEC

SIGNAL #7 DC LEVEL SHIFT
SIGNAL #9 MODULATED 1000 CPS CARRIER

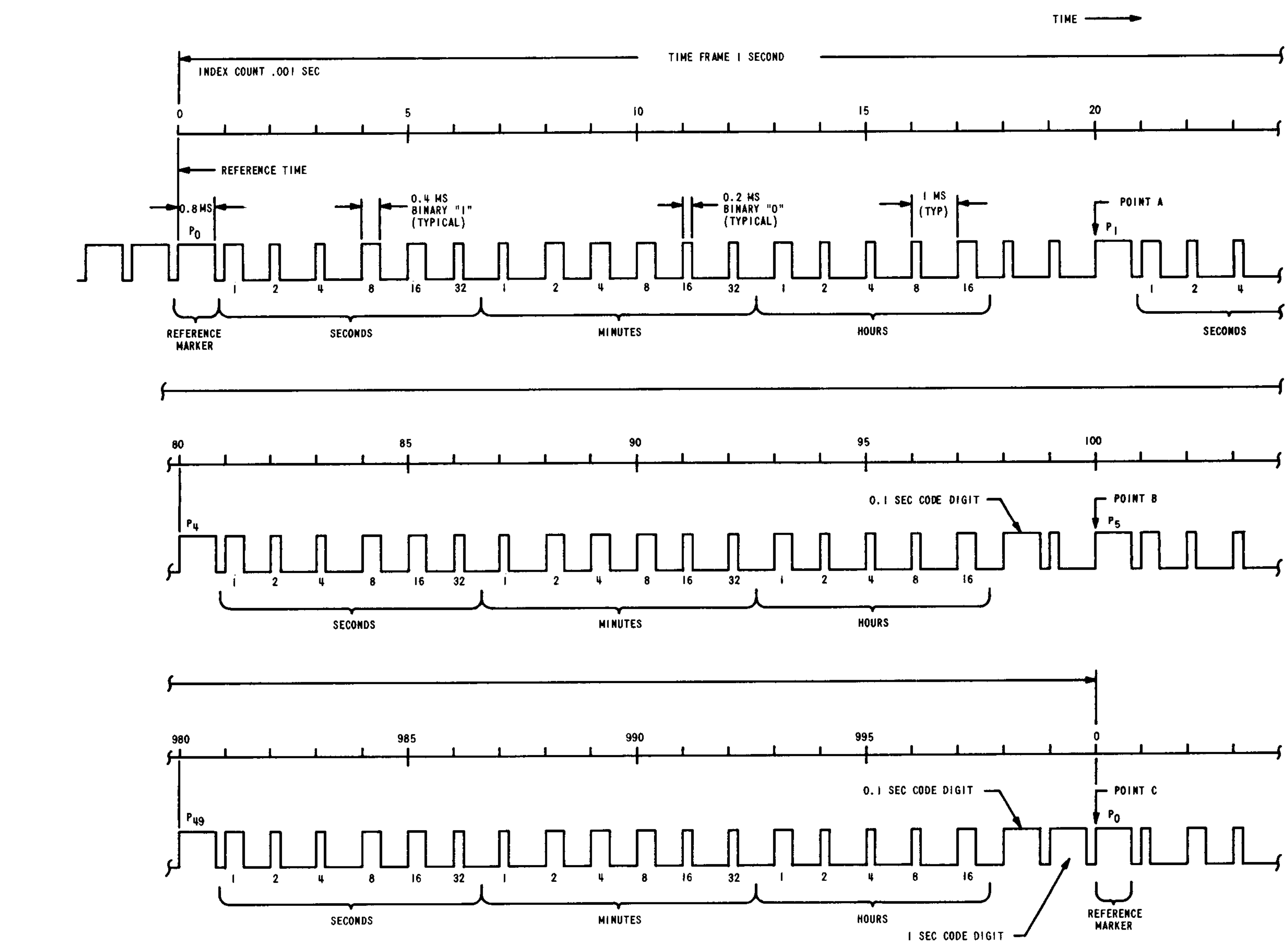
TITLE: APGC EGLIN TIME CODE SIGNAL #7 & #9 1 PPS	DRAWN BY: OLDEWAGE	DATE: 2FEB65	PROJ
	PUBLICATIONS	6 MAY 65	SHEET OF 19.0
	PROJECT ENGR	6 MAY 65	
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA	GROUP ENGR / CHIEF ENGR		DWG. NO. A35100



TIME AT POINT A = 2X(4+16+1024+2048+4096+8192)+1+.2
=30761.2 SECONDS

MODULATED CARRIER ENVELOPE - CARRIER 1000 CPS

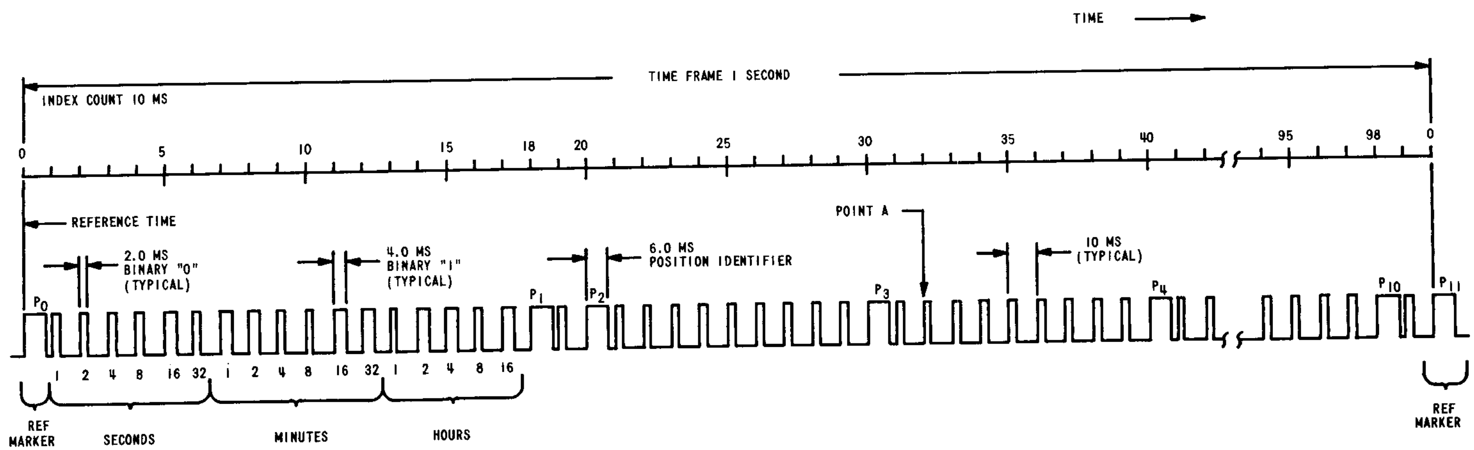
TITLE	CHECKED	DRAWN BY	DATE	PROJ
PMR 16 BIT TIME CODE 10 PPS	ENGINEER	OLDEWAGE PUBLICATIONS	2FEB65 6 MAY 65	SHEET OF 20.0
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA	PROJECT ENGR CHIEF ENGINEER CHIEF ENGR			DWG. NO. A35100



TIME AT POINT A = 17 HR., 14 MIN., 25.02 SEC
B = 17 HR., 14 MIN., 25.1 SEC
C = 17 HR., 14 MIN., 26 SEC

TITLE			
AFFTC EDWARDS CENTER FORMAT A 1000 PPS	CHECKED	DRAWN BY OLDEWAGE	DATE 3FEB65
	ENGINEER	PUBLICATIONS	6 MAY 65
	PROJECT ENGR		6 MAY 65
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA	GROUP ENGR		
	CHIEF ENGR		

PROJ
SHEET 21.0 OF
DWG. NO. A35100

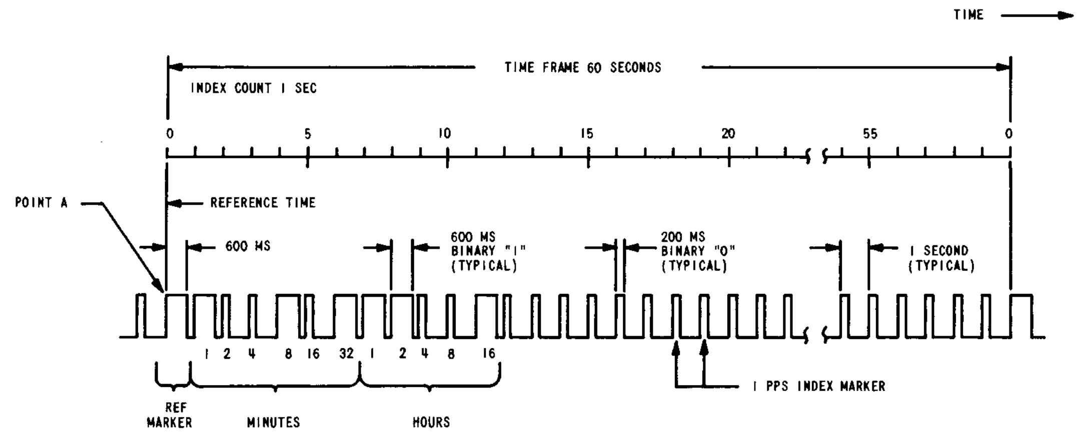


TIME AT POINT A: 22 HOURS, 51 MINUTES, 16.32 SECONDS

TITLE AFFTC EDWARDS CENTER FORMAT B
100 PPS

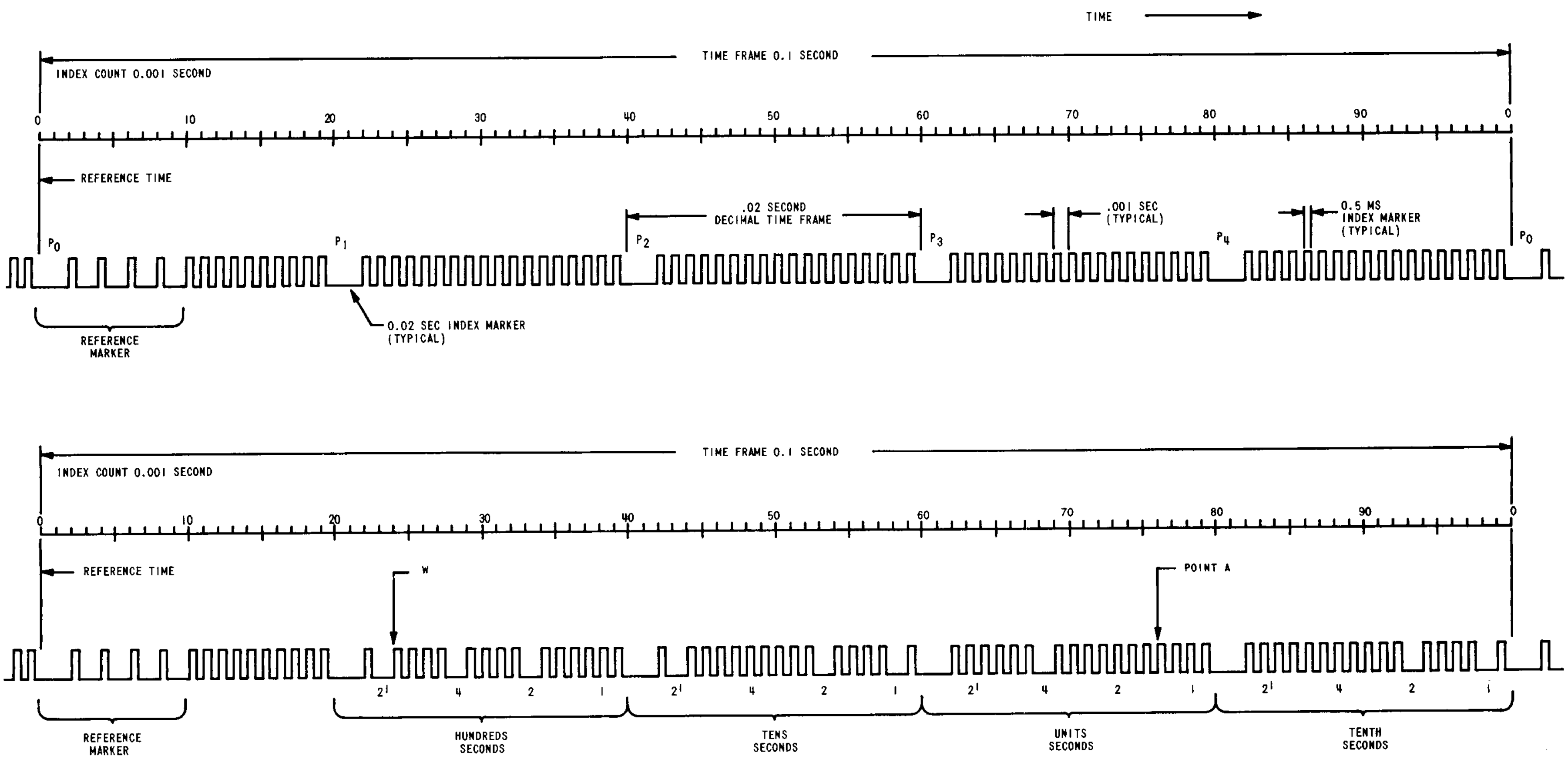
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA
SANTA ANA

DRAWN BY OLDEWAGE
DATE 15APR65
6 MAY 65
6 MAY 65
PROJ
SHEET OF 22.0
DWG. NO. A35100



TIME AT POINT A: 19 HOURS, 41 MINUTES, 0 SECONDS

TITLE AFFTC EDWARDS CENTER FORMAT C 1 PPS	CHECKED / DRAWN BY OLDEWAGE	DATE 15APR65	PROJ
		6 MAY 65	SHEET OF 23.0
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA		6 MAY 65	DWG. NO. A35100



REFERENCE MARKER = 0.1 SEC, 0.02 SEC INDEX MARKER WITH THE 2nd,4th,6th, and 8th 0.001 SEC INDEX MARKERS THEREAFTER MISSING

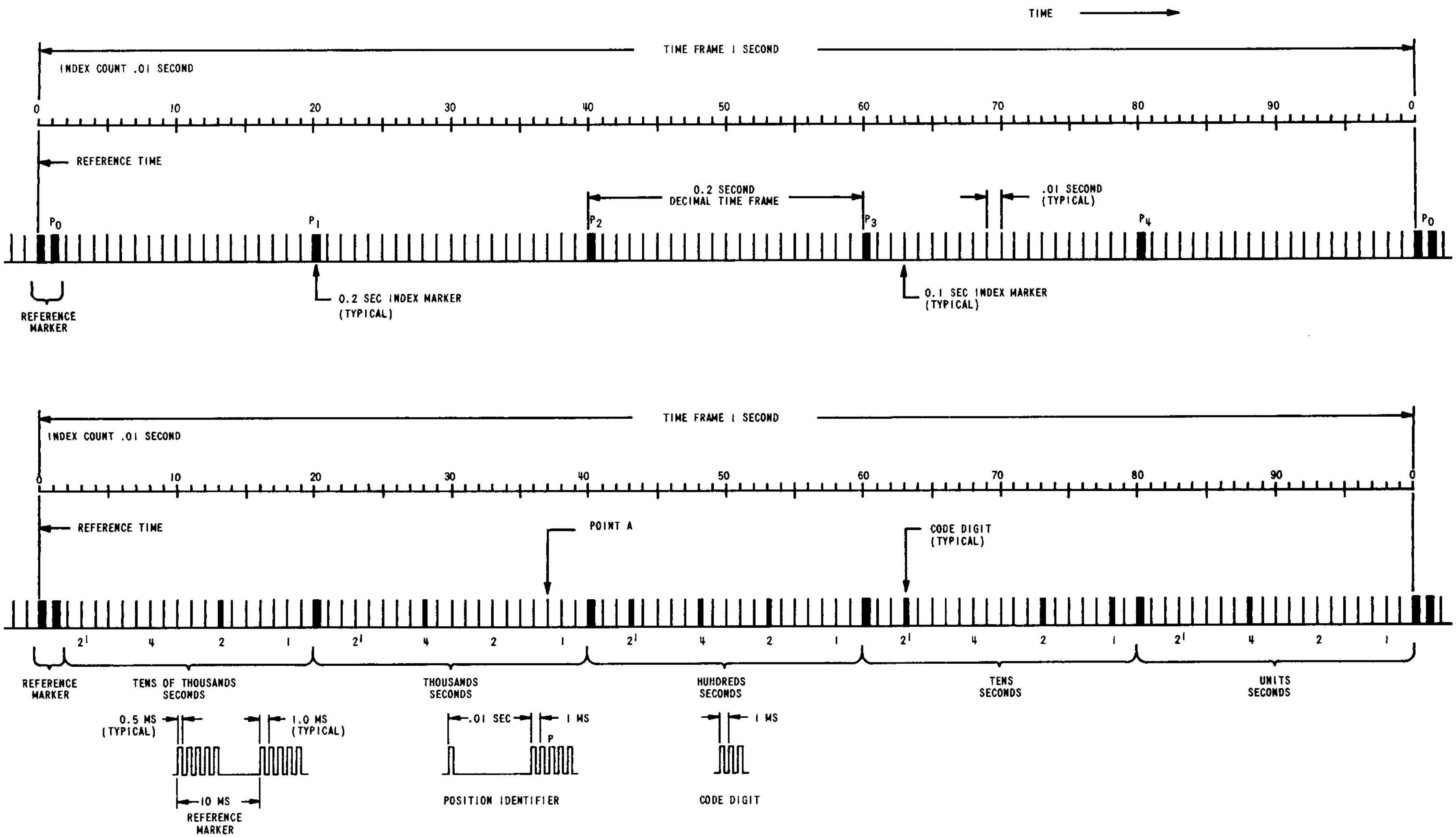
P=POSITION IDENTIFIERS AND 0.02 SEC INDEX MARKER, 2 MISSING CONSECUTIVE PULSES OF THE BASIC ELEMENT RATE. ON TIME POINT IS THE LEADING EDGE OF THE FIRST MISSING PULSE.

W=WEIGHTED CODE DIGIT, 1 MISSING PULSE OF THE BASIC ELEMENT RATE MUST OCCUR AT 3rd,8th,13th, and 18th, 0.001 INDEX COUNT DURATION OF 0.001 SEC INDEX MARKERS = 0.5 MS

TIME AT POINT A: 800+50+4+.3+.06+.016

=854.376

TITLE: WHITE SANDS G-1 FORMAT 1000 PPS	DRAWN BY: OLDENAGE	DATE: 15APR65	PROJ
	PUBLICATIONS	6 MAY 65	SHEET OF 24.0
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA, SANTA ANA	PROJECT ENGR	6 MAY 65	DWG. NO. A35100



P=POSITION IDENTIFIER, 5 PULSES AT A 1K PPS RATE

REFERENCE MARKER = 1.0 SEC TWO CONSECUTIVE POSITION IDENTIFIERS. THE ON TIME POINT IS THE LEADING EDGE OF THE FIRST PULSE IN THE FIRST POSITION IDENTIFIER

DURATION OF ALL PULSES = 0.5 MS

CODE DIGIT = 0.01 INDEX MARKER FOLLOWED BY TWO ADDITIONAL 0.5 MS WIDE PILSES AT 1 MS INTERVALS. MUST OCCUR AT 3rd. 8th, 13th, and 18th INDEX COUNTS WITHIN A DECIMAL TIME FRAME

TIME AT POINT A: 20,000 + 4,000 + 800 + 50 + 4 + 0.2 + 0.17

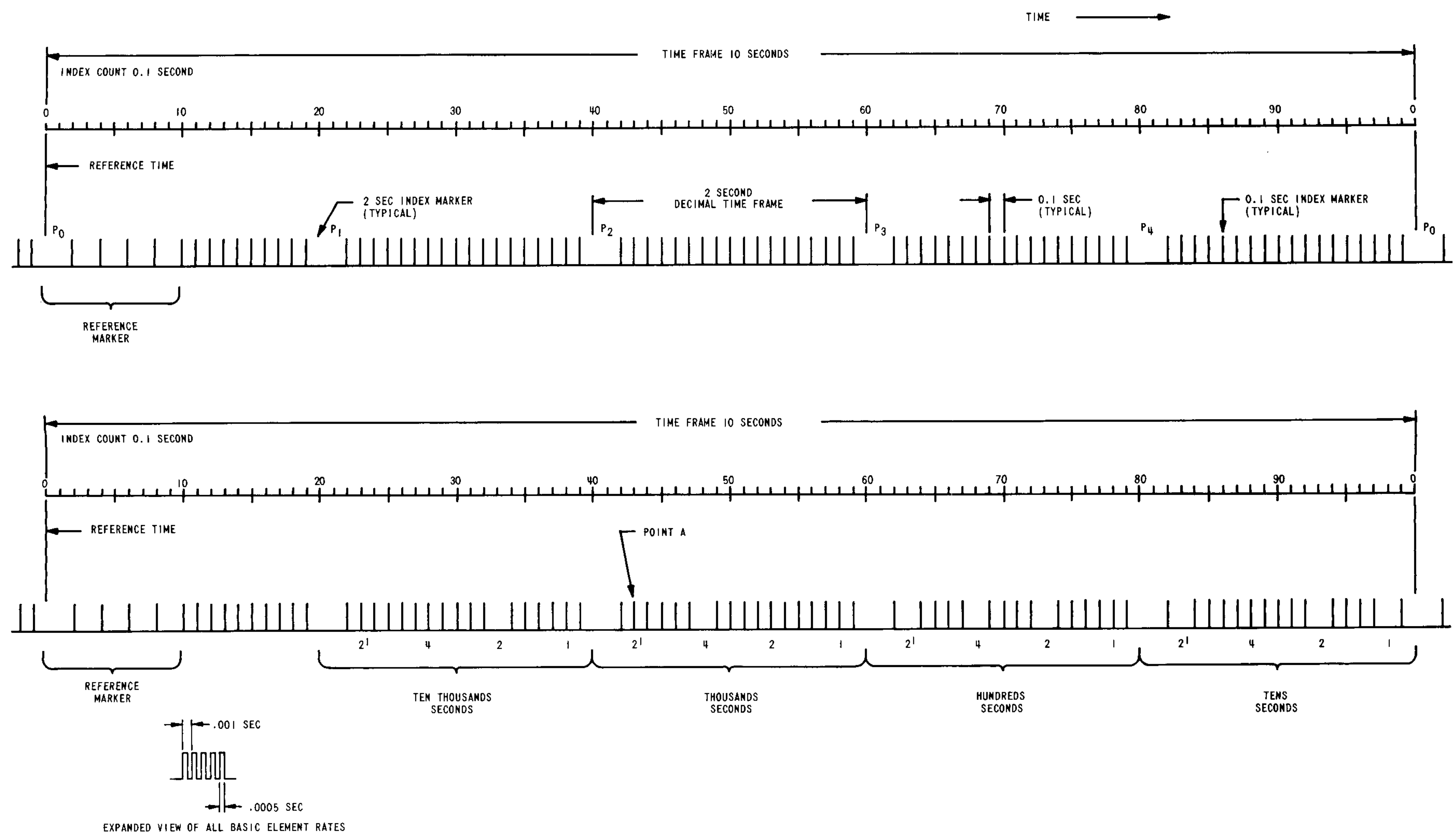
= 24,854.37 PLUS

TITLE WHITE SANDS G-2 FORMAT
100 PPS

ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA
SANTA ANA

CHECKED | DRAFTSMAN OLDENAGE | DATE 15APR65
ENGINEER | PUBLICATIONS | 6 MAY 65
PROJECT ENGR | | 6 MAY 65
GROUP ENGR
CHIEF ENGR

PROJ
SHEET OF 25.0
DWG. NO. A35100



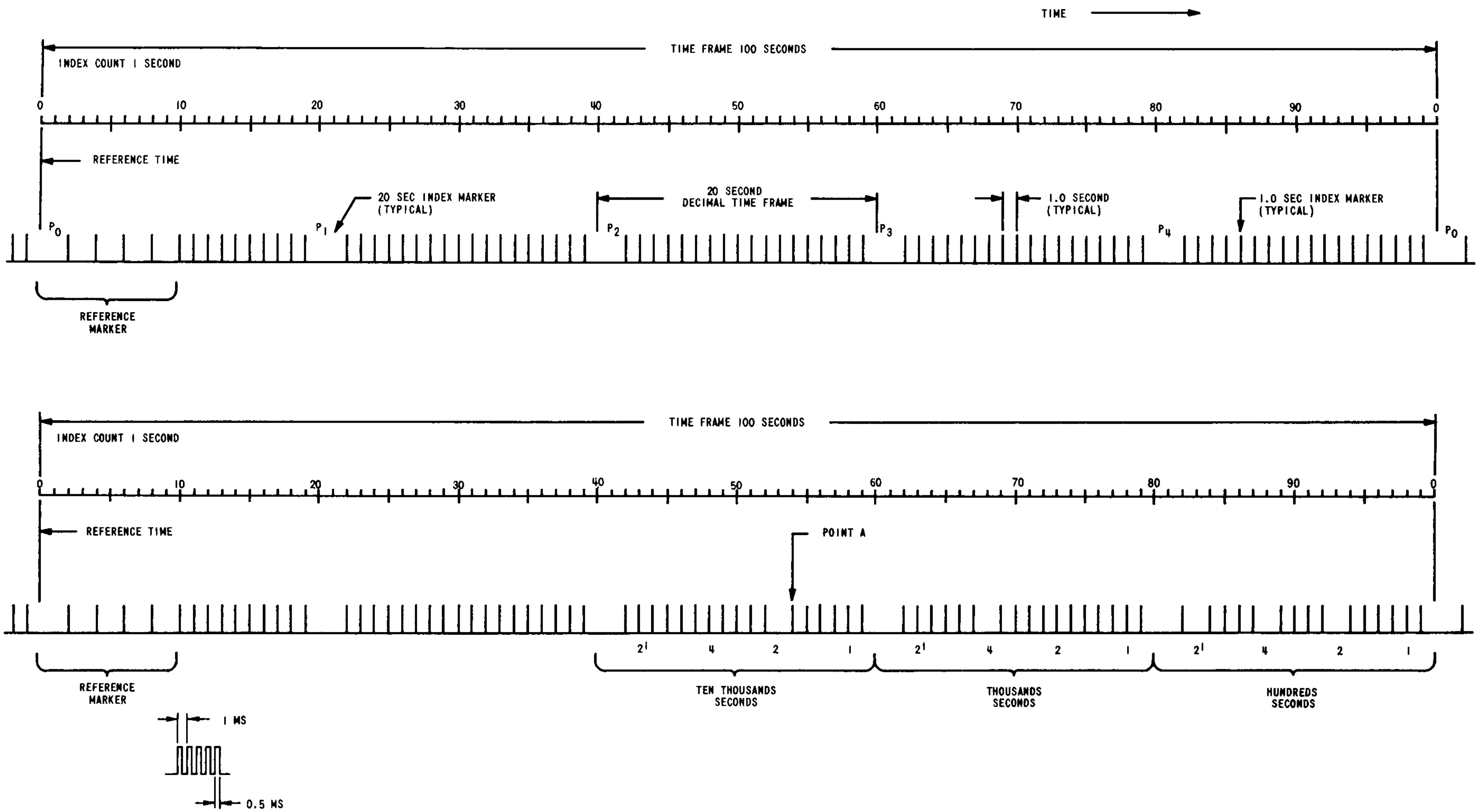
REFERENCE MARKER = 10 SEC A POSITION IDENTIFIER WITH THE 2nd.4th.6th.and 8th 0.1 SEC INDEX MARKER THEREAFTER MISSING. THE ON TIME POINT IS THE LEADING EDGE OF THE FIRST PULSE IN THE FIRST POSITION IDENTIFIER.

P = POSITION IDENTIFIER. 2 MISSING CONSECUTIVE BASIC ELEMENT RATES. THE ON TIME POINT IS THE LEADING EDGE OF THE FIRST MISSING PULSE A WEIGHTED CODE DIGIT IS INDICATED BY A SINGLE MISSING 0.1 SEC INDEX MARKER (MUST OCCUR AT THE 3rd.8th.13th. or 18th INDEX COUNTS WITHIN A DECIMAL TIME FRAME

TIME AT POINT A: 20,000 + 4,000 + 800 + 50 + 4 + 0.3

= 24,854.3 PLUS

TITLE	CHECKED	DRAWN BY OLDENAGE	DATE 15APR65	PROJ
WHITE SANDS G-3 FORMAT 10 PPS	ENGINEER	PUBLICATIONS	6 MAY 65	SHEET OF 26.0
	PROJECT ENGR		6 MAY 65	
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA	GROUP ENGR / CHIEF ENGR			DWG. NO. A35100



REFERENCE MARKER = 100 SEC. A POSITION IDENTIFIER WITH THE 2nd,4th,6th, and 8th 1.0 SEC INDEX MARKER THEREAFTER MISSING. THE ON TIME POINT IS 1 MS AHEAD OF THE LEADING EDGE OF THE FIRST POSITION IDENTIFIER.

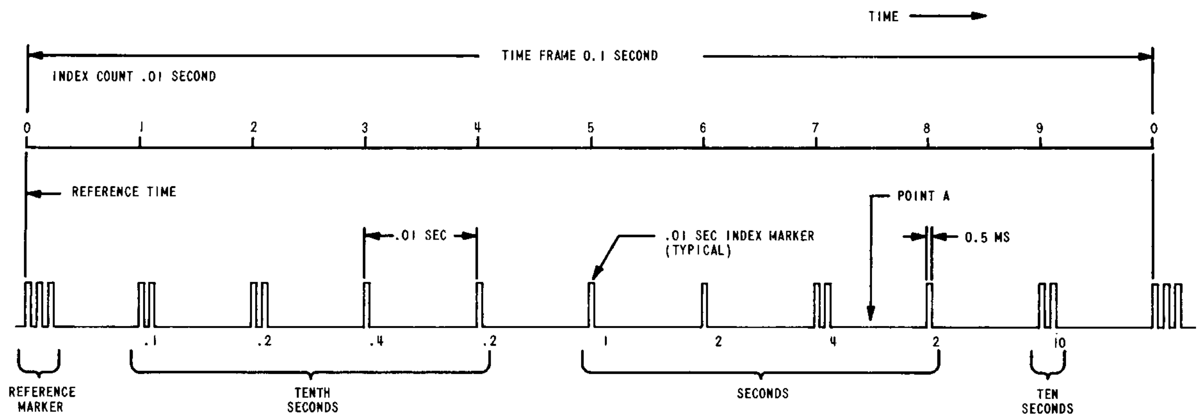
P = POSITION IDENTIFIER, 2 MISSING CONSECUTIVE BASIC ELEMENT RATES. THE ON TIME POINT IS 1 MS AHEAD OF THE LEADING EDGE OF THE FIRST MISSING PULSE.

A WEIGHTED CODE DIGIT IS INDICATED BY A SINGLE MISSING 1 SEC INDEX MARKER. (MUST OCCUR IN THE 3rd,8th,13th or 18th INDEX COUNTS WITHIN A DECIMAL TIME FRAME.

TIME AT POINT A: 20,000 + 4,000 + 800 +40 +14

= 24,854 PLUS

TITLE	CHECKED	OLDENAGE	15APR65	PROJ
WHITE SANDS G-4 FORMAT 1 PPS	PUBLICATIONS		6 MAY 65	SHEET OF 27.0
	PROJECT ENGR		6 MAY 65	
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA	GROUP ENGR			DWG NO. A35100
	CHIEF ENGR			



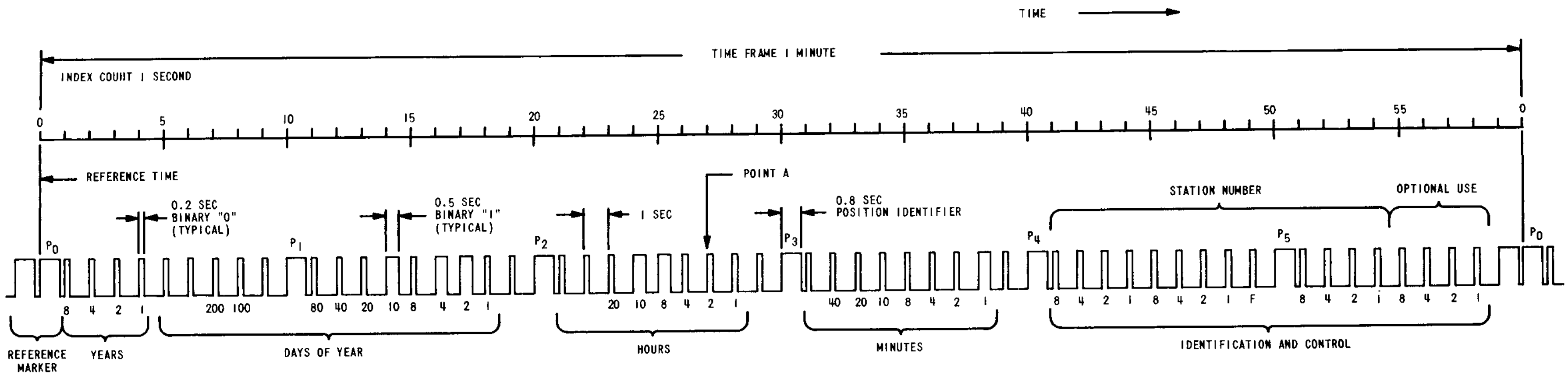
TIME AT POINT A: 10 +4 + 0.3 + .07

= 14.37 PLUS

REFERENCE MARKER = A 0.01 SEC INDEX MARKER FOLLOWED BY TWO ADDITIONAL 0.5 MS PULSES AT 1 MS INTERVALS

CODE DIGIT = A 0.01 SEC INDEX MARKER FOLLOWED BY A SINGLE ADDITIONAL 0.5 MS PULSE A MILLISECOND LATER

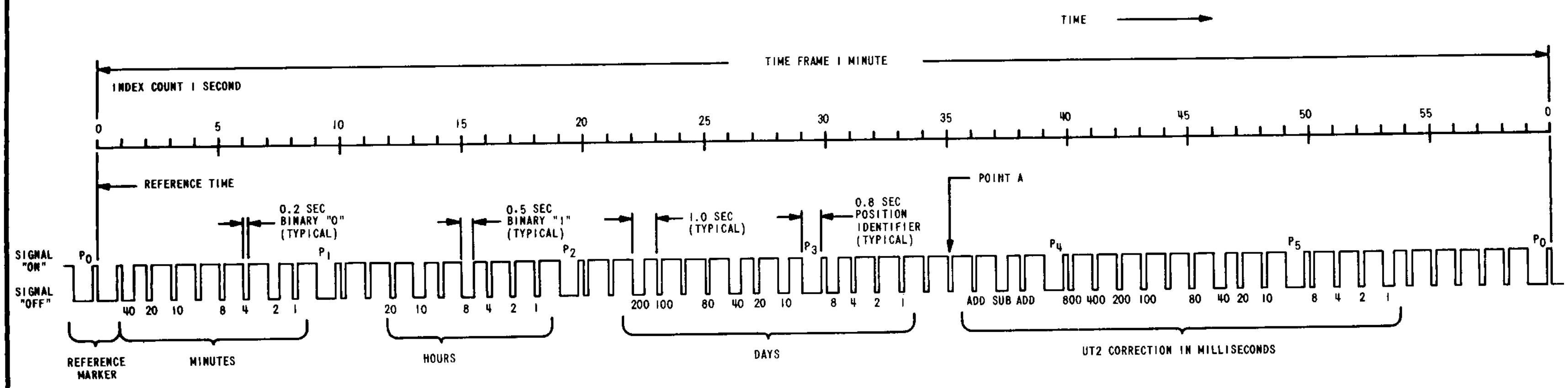
TITLE WHITE SANDS G-8 FORMAT 100 PPS	CHECKED / DRAWN BY OLDEVAGE	DATE 15APR65	PROJ
	ENGINEER / PUBLICATIONS	6 MAY 65	SHEET OF 28.0
	PROJECT ENGR	6 MAY 65	
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA	GROUP ENGR		DWG NO. A35100
	CHIEF ENGR		



TIME AT POINT A: 0 YEAR, 16 DAYS, 18 HOURS, 1 MINUTE, 27 SECONDS

FLAG BIT - F DENOTES ABNORMAL RECORDING FORMAT WHEN VALUE IS "ONE" (SEE INDEX COUNT 49)

TITLE VELA TIME CODE 1 PPS	DRAWN BY OLDEWAGE	DATE 15APR65	PROJ
			SHEET OF 29.0
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA			DWG. NO. A35100



TIME AT POINT A: 258 DAYS, 18 HOURS, 42 MINUTES, 35 SECONDS.

SUBTRACT 41 MILLISECONDS

REV	CHANGE	DATE	APPD
A	REVISED PER NBS	9-12-65	

TITLE: NBS TIME CODE FORMAT WWVB 1 PPS

ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA
SANTA ANA

OLDEHAGE 15APR65

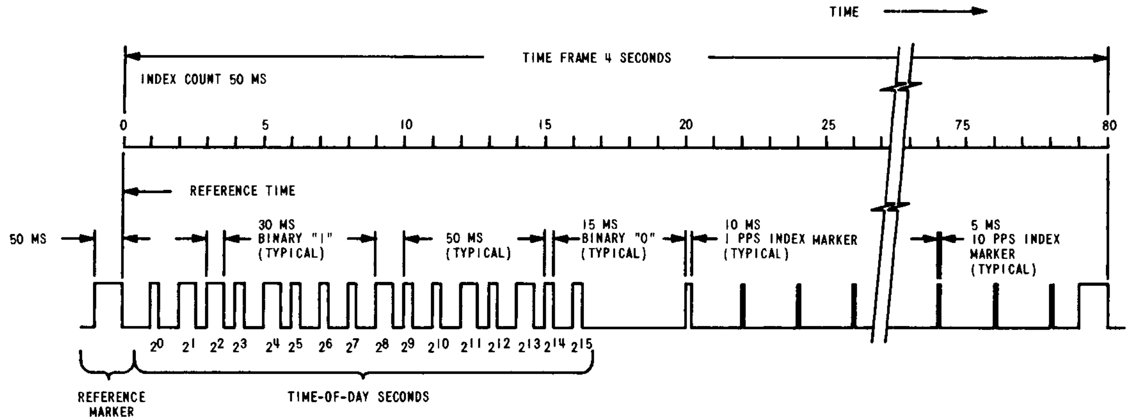
6 MAY 65

6 MAY 65

PROJ

SHEET OF 30.0

A35100 A



TIME AT REFERENCE MARKER: 8192 + 2048 + 256 + 16 + 4 + 2

= 10,518 SECONDS

TITLE

PHILCO TYPE A
20 PPS

ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA
SANTA ANA

DRAWN BY OLDEYAGE

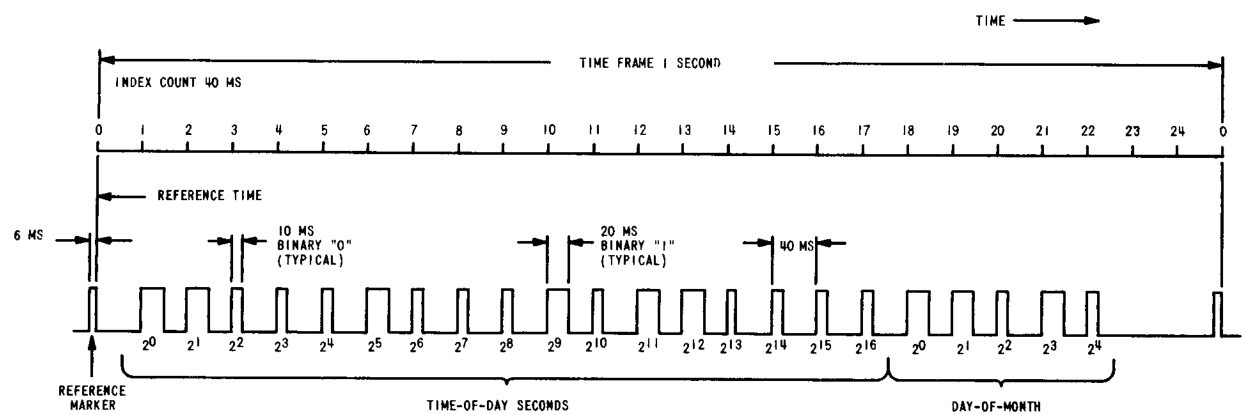
DATE 15APR65

6 MAY 65

10 MAY 65

SHEET 31.0

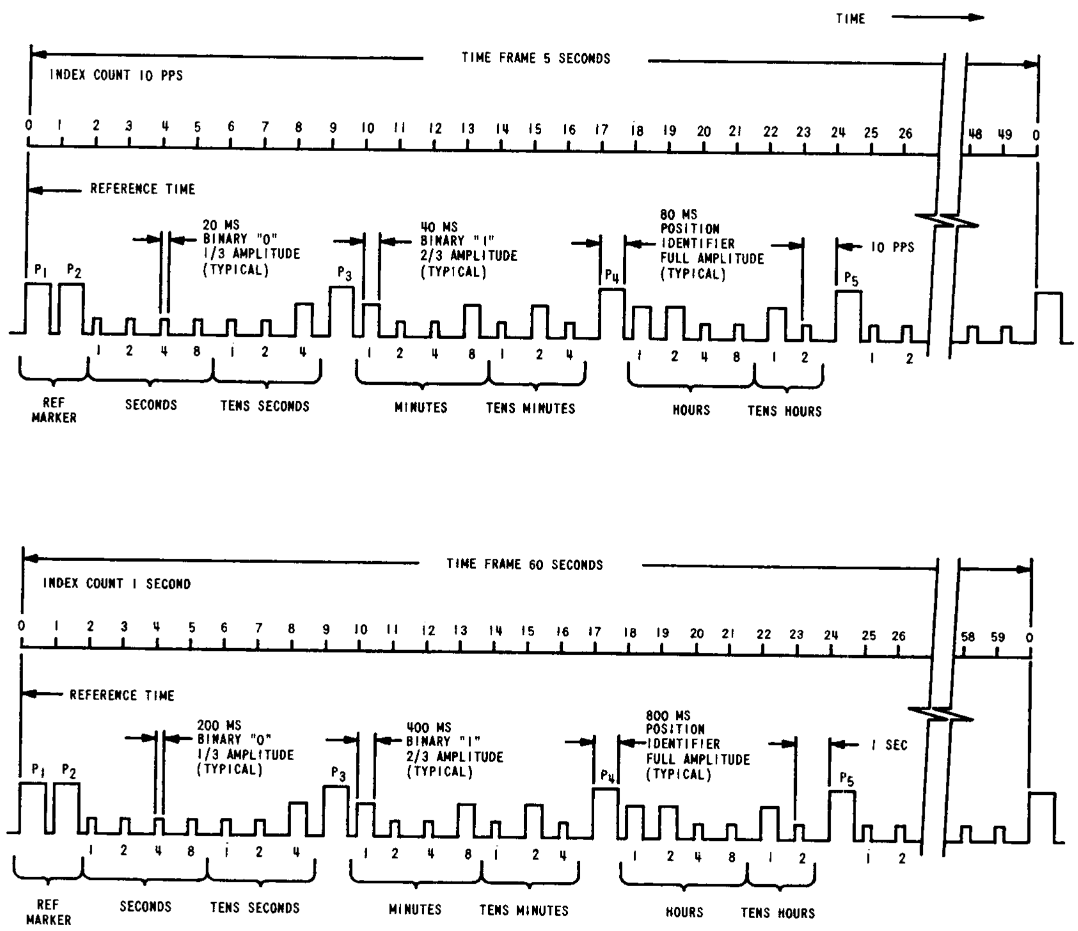
DWG. NO. A35100



TIME AT REFERENCE MARKER: 11 DAYS + 4096 + 2048 + 512 + 32 + 2 + 1 SECONDS

= 11 DAYS 6691 SECONDS

TITLE PHILCO TYPE B 25 PPS	CHECKED	DRAWN BY OLDEVAGE PUBLICATIONS	DATE 15APR65	PROJ
	RELEASED		6 MAY 65	SHEET OF 32.0
	PROJECT ENGR		6 MAY 65	
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA	GROUP ENGR			DWG. NO. A35100
	CHIEF ENGR			



TIME SHOWN: 13 HOURS, 29 MINUTES, 40 SECONDS

TITLE			
EECO 056 LEVEL SHIFT	OLDEWAGE	4 MAY 65	PROJ
		6 MAY 65	SHEET 33.0 OF
		6 MAY 65	DWG. NO. A25100
ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA SANTA ANA			

APPENDIX II

Timing Pulse Jitter Due to Low Frequency Response Limitations

TIMING PULSE JITTER DUE TO LOW FREQUENCY RESPONSE LIMITATIONS

for

ELECTRONIC ENGINEERING COMPANY

13 May, 1965

COMMUNICATIONS RESEARCH LABORATORIES
14141 Stratton Way
Santa Ana, California 92705

ANALYSIS OF TIME JITTER DUE TO LIMITED LOW FREQUENCY RESPONSE

In Magnetic Tape Recording or Phone-line transmission of timing signals where low-frequency response is limited, it is customary to transmit the timing pulses as modulation on a suitable subcarrier. The purpose of this analysis is to investigate the often overlooked effects of limited channel low-frequency response on timing error.

As a first example, we will take the IRIG A,B,C,D formats. (Ref.1) The specifications are:

		Format			
		A	B	C	D
Subcarrier frequency,	f_s	10 KC	1 KC	100 v	100 v
Pulse (element) rate,	f_e	1 KC	100/sec	2/sec	1/min
"0" element length,	τ_0	.2 ms	2 ms	.1 sec	12 sec
"1" element length,	τ_1	.5 ms	5 ms	.25 sec	30 sec
Position identifier length,	τ_2	.8 ms	8 ms	.4 sec	48 sec

Normally when subcarrier modulation is used the modulation is between amplitudes of about 1/3 and 1 relative units, the latter being "on". We may compute the transient resulting from a modulation turn "on" by the analysis of the following simplified waveform, i.e., simply a turn on.

$$E(t) = \begin{cases} 0 & t < 0 \\ \sin \omega t & t > 0 \end{cases}$$

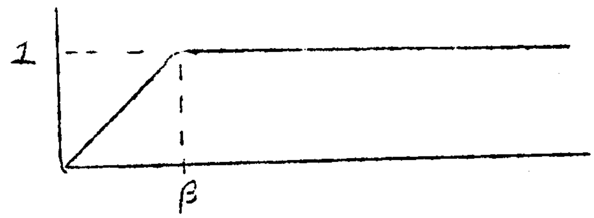
The La Place transform of this is

$$E(s) = \frac{\omega}{s^2 + \omega^2}$$

Ref.1. "IRIG Standard Time Formats", IRIG Document No. 104-60.

Now we may consider the effect of a low-frequency cutoff, idealizing the transfer function as

$$Y_1(s) = \frac{s}{s+\beta}$$



Then the filtered transient is

$$E(s) = \frac{\omega s}{(S^2+\omega^2)(s+\beta)}$$

or in the time domain, by the inverse transform

$$E(t) = -\frac{\beta\omega}{\omega^2+\beta^2}\, e^{-\beta t} + \left[\frac{\omega^2}{\omega^2+\beta^2}\right]^{1/2} \operatorname{Sin}\left[\omega t + \psi\right]$$

where $\quad \psi = \frac{\pi}{2} - \operatorname{Tan}^{-1}\left(\frac{\omega}{\beta}\right)$

$$= \operatorname{Tan}^{-1}\left(\frac{\beta}{\omega}\right)$$

or, defining $\quad \rho = \frac{\beta}{\omega} \quad$ (normally $\ll 1$)

$$E(t) = -\frac{\rho}{1+\rho^2}\, e^{-\beta t} + \frac{1}{\sqrt{1+\rho^2}} \operatorname{Sin}\left[\omega t + \operatorname{Tan}^{-1}\rho\right]$$

In the usual modulation convention, the constant underlying carrier (called the base) is of amplitude A/3 and the transient part is of amplitude 2A/3 for a total of A (peak). The first, or transient, term above thus has amplitude $\frac{2A}{3}$ while for the total waveform, the second or steady state term has amplitude A.

$$E_T(t) = -\frac{2A\rho}{3(1+\rho^2)}\, e^{-\beta t} + \frac{A}{\sqrt{1+\rho^2}} \operatorname{Sin}(\omega t + \operatorname{Tan}^{-1}\rho)$$

Now we are interested in the effect of the transient on the positive zero-crossing times of the composite waveform. These times are the solutions of

$$E_T(t) = 0$$

or

$$\mathrm{Sin}\,(\omega t + \mathrm{Tan}^{-1}\rho) = \frac{2}{3}\,\frac{\rho}{\sqrt{1+\rho^2}}\,e^{-\beta t}$$

In the steady state, i.e., after the transient has died out, these times are just the times τ given by

$$(\omega\tau + \mathrm{Tan}^{-1}\rho) = n2\pi$$

So it is useful to expand the Sin function around this point

$$\mathrm{Sin}\,\left[n2\pi + \omega(t-\tau)\right] = \frac{2}{3}\,\frac{\rho}{\sqrt{1+\rho^2}}\,e^{-\beta t}$$

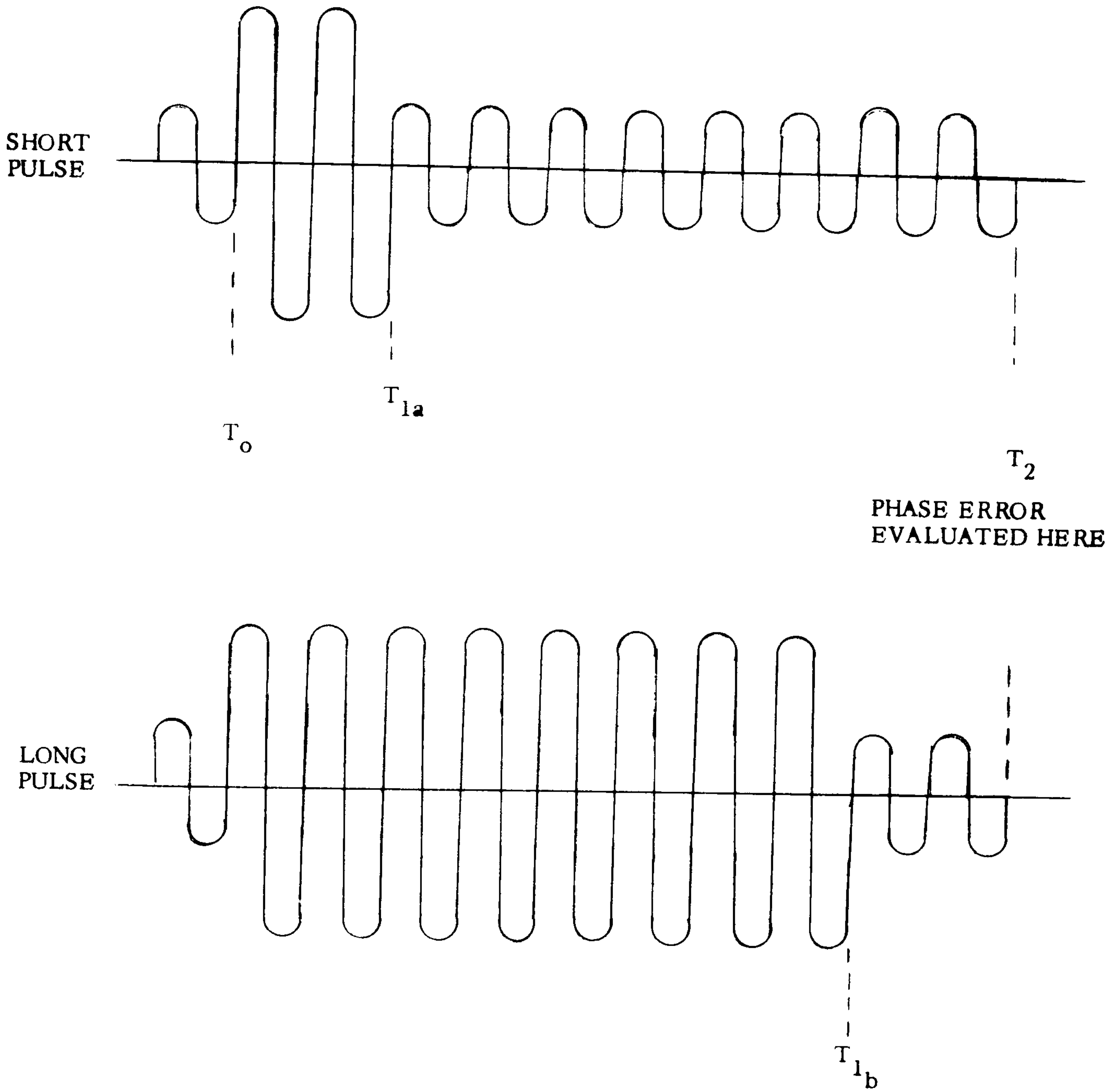
and if $\omega(t-\tau)$ small (i.e., small phase error)

$$\Delta\phi = \omega\,(t-\tau) = \frac{2}{3}\,\frac{\rho}{\sqrt{1+\rho^2}}\,e^{-\beta t}$$

The critical times are those at the beginning of a new element and here the total phase error may be represented as a summation over all the "on" and "off" step transients left over from all preceding modulation steps and thus depends on the entire prior history. A limiting value for the jitter here may be fairly inferred, however, by the difference in the effect of the just prior pulse being a "0" (2 cycles long) or a "position identifier" (8 cycles long). Thus, we will assume, following the B format, a positive step modulation at $T_o = 0$, a negative step modulation at

$$T_1 = \begin{cases} 2\text{ ms} & \text{for "0"} \\ \text{or} & \\ 8\text{ ms} & \text{for "position"} \end{cases}$$

and evaluate the resulting total error at $T_2 = 10$ ms (next time pulse) as depicted in Figure 1.



EXTREME PULSES FOR
EVALUATION OF PULSE JITTER
DUE TO PRECEEDING PULSE HANGOVER

FIGURE 1

The resulting phase error may be expressed (still assuming that the phase errors are small enough to add linearly)

$$\Delta\phi = \Delta\phi(T_2 - T_o) - \Delta\phi(T_2 - T_1)$$

$$= \frac{2}{3}\frac{\rho}{\sqrt{1+\rho^2}}\left[e^{-\beta(T_2 - T_o)} - e^{-\beta(T_2 - T_1)}\right]$$

This is converted to time difference error by dividing by the subcarrier angular frequency to give the estimate of maximum time jitter due to previous pulse hangover

$$\Delta T = \frac{\Delta\phi}{\omega}$$

$$= \frac{2}{3}\frac{\rho}{\omega\sqrt{1+\rho^2}}\left[e^{-\beta(T_2 - T_o)} - e^{-\beta(T_2 - T_1)}\right]$$

The behaviour depicted in Fig. 1 is interesting in that the error is small for both large and small f_c (in the first case because, although a large transient is excited, it has pretty well died out by the time of the next element, and in the second case because only a very small transient is excited. The worst case occurs in the vicinity of 100 cps low frequency cutoff which is unfortunately rather typical of direct analog tape recording response. It is to be emphasized that there are practical circumstances in which 2 - 3 usec relative, short-term time jitter on 100/sec timing pulses is very serious, particularly in connection with Doppler or other velocity measuring systems.

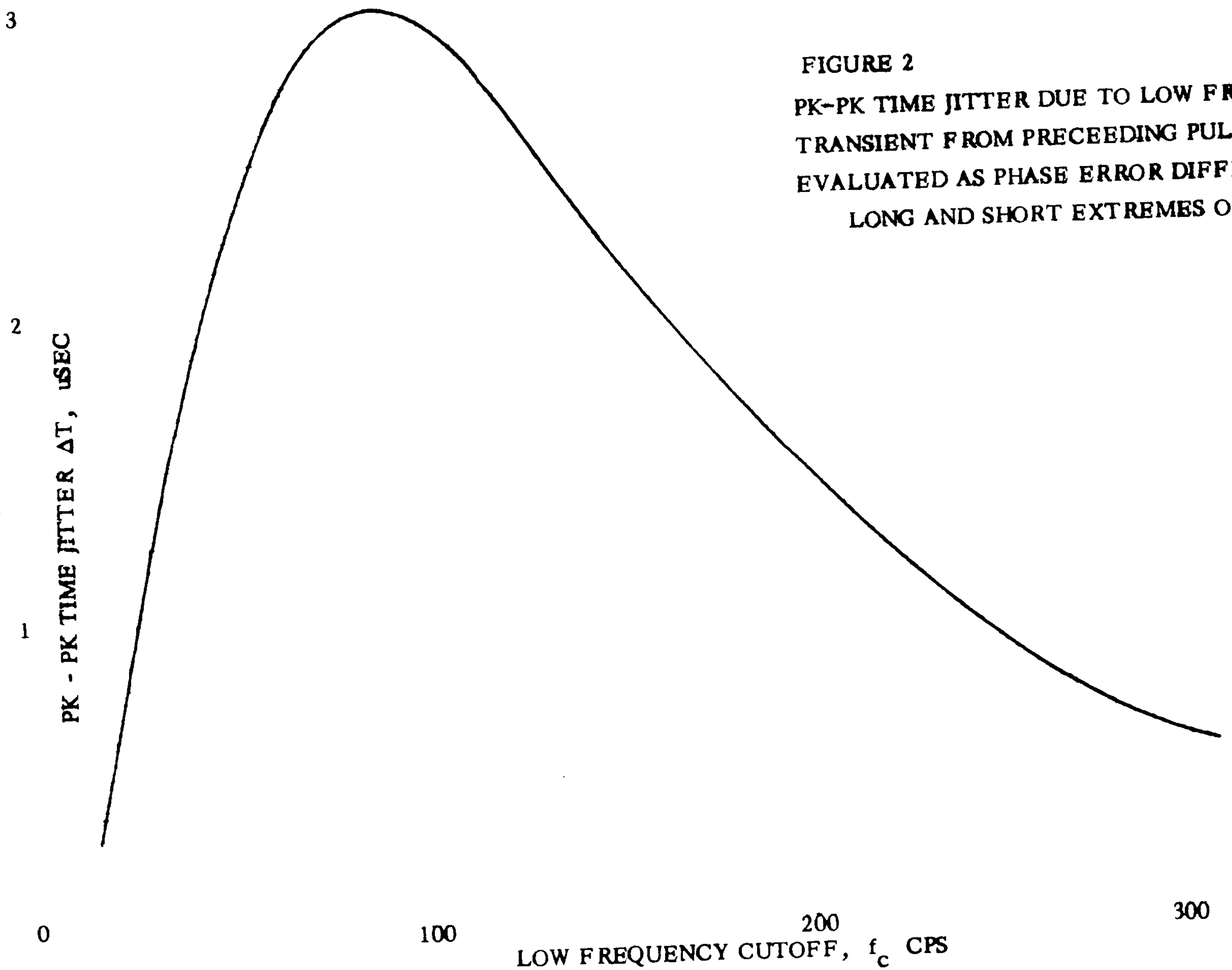


FIGURE 2
PK-PK TIME JITTER DUE TO LOW FREQUENCY CUTOFF
TRANSIENT FROM PRECEEDING PULSE
EVALUATED AS PHASE ERROR DIFFERENCE FOR
LONG AND SHORT EXTREMES OF PRECEEDING PULSE

SUPPLEMENTARY MATERIAL
FIRST SEMIANNUAL REPORT
for
TIME CODE STUDY
(15 Sept 1964 - 28 May 1965)

Contract No. NAS5-9739

General

The purpose of this material is to expand certain ideas presented in the First Semiannual Report. These ideas are presented by subject in the order that they are found in the report and are referenced to a particular section in the report. Material describing timing systems in use at the various test ranges and data gathering facilities will be included in the Final Report.

Time Code Generator Precision Frequency Signal Sources (page 5)

Crystal oscillators and atomic oscillators are normally used in providing the basic precision signal for time generation. The basic characteristics of each are listed below:

1. Crystal Controlled Oscillators.

   Crystal oscillators used as precision frequency sources have the following important characteristics.

   a. Drift Rate (aging) --Typically rated in terms of frequency change in 24 hours time. As an example, a one megacycle oscillator having a drift rate of 1×10^{-10} per day will have changed from a frequency of 1,000,000 cps to 1,000,000.0001 cps in one day. Such an oscillator, if not corrected for one year, would differ from its initial frequency by 3.65 parts in 10^8 and would now have a frequency of 1,000,000.0365 cycles per second.

b. Change of frequency with changing environmental conditions.

(1) Temperature

(2) Supply voltage

(3) Output loading

c. Settability -- The precision and predictability with which the oscillator's frequency can be changed. As an example, one commercially available oscillator has an output frequency adjustment which provides approximately 1 part in 10^{10} per division with a total adjustment range of 1000 parts in 10^{10}.

Settability is particularily important when the crystal oscillator is being compared against, and corrected to, a primary standard such as VLF frequencies radiated by the National Bureau of Standards. Daily frequency corrections of predictable amounts can be applied to the crystal oscillators to compensate for the frequency deviation due to aging.

2. Atomic Oscillators

Rubidium gas cell referenced oscillators and cesium beam referenced oscillators use crystal oscillators whose frequency of oscillation is phase-locked to an atomic transition. These oscillators have typical long-term (one year) frequency stabilities of 5 parts in 10^{11}. Commercially available moderate cost oscillators of this type can be referenced to VLF standard frequency transmission and after an initial monitoring and adjustment period, can maintain a ±1 microsecond per day phase relationship to the VLF standard frequency transmission.

Synchronization of Time Code Generators by Manual versus Automatic Methods (page 9)

The problems of synchronizing a time code generator to a given time reference signal vary considerably depending on such factors as the signal-to-noise ratio of the reference information, and the length of time over which the time code generator can be expected to operate without accumulating an excessive time error.

1. Synchronization from other Time Code Generators.

   When the time reference signal is a pulse train from another time code generator, then the signal-to-noise ratio will be extremely good and it would be quite feasible to automatically adjust time code generator B to have the desired time relationship to time code generator A.

2. Synchronization from WWV

   When the time reference signal is in the form of a received radio frequency signal such as the WWV "time tick," manual synchronization with a human operator interpreting the time relationship between the locally generated 1 pulse per second signal and the time of arrival of the WWV time tick is usually required. The trained operator can exercise a degree of selection of received pulses to be used for comparison, and pulses to be ignored on the basis that they have been severely distorted in the radio transmission process. Design of automatic WWV "time tick" recognition circuitry with the same degree of intelligence as that exercised by a trained operator would be an extremely difficult task.

3. Synchronization from Loran-C.

Radio frequency pulses radiated at 100 kc by the East Coast chain of the Loran-C navigation system provide a time reference which is more stable than the received WWV time tick when the user is outside the ground range coverage area of the WWV transmitters (estimated to be a radius of 30 to 50 miles from the transmitter).

The rapid rise time (50% amplitude in 35 microseconds) of the Loran-C pulse allows the ground wave signal to be sampled near its 50% amplitude point without contamination by the sky wave signal whose time of arrival is typically 40 to 60 microseconds later than the ground wave signal.

This time selective ability to sample the ground wave signal without sky wave contamination plus the comparatively low attenuation of the 100 kc ground wave means that the ground wave signal can be accurately processed by elaborate tracking receivers at distances up to 1000 miles from the Loran-C transmitter.

Although Loran-C stations (chains) exist in many parts of the world, at present only the East Coast chain has a repetition rate that provides an integral number of pulses in a useable time period (25 pulse groups per 2 seconds). Pulse group repetition period is $\frac{2 \times 10^6}{25} = 80{,}000$ micro-seconds.

The East Coast chain cosnists of a master station located at Cape Fear, North Carolina and three operational slave stations located at Jupiter Inlet, Florida; Nantucket, Massachusetts; and Cape Race, Newfoundland.

usable 24-hour-a-day real time reference for users within a radius of 1200 to 1500 nautical miles. Users at distances in excess of 1500 miles will normally have usable signals available only when a substantial part of the propagation path is in darkness.

Although it is feasible to implement an automatic synchronization system with a tracking receiver operating on a ground wave signal, it is felt that best results can be obtained using manual techniques.

4. Synchronization with a Traveling Clock

Synchronization by means of a traveling clock is done manually primarily because of the secondary correction which is usually required after the loop has been closed and the clock performance has been interpolated for the various points visited in the trip.

Simultaneity of Generator Outputs (page 15)

Time code generators operating from a one megacycle input will have six N/10 dividers using 24 flip flops to divide the one megacycle rate to a one pulse per second rate. These same generators will use a minimum of 30 flip flops in 9 divider sections to accumulate seconds, minutes, hours, and days for a total of one year's time. In the usual accumulator arrangement, each divider section is triggered by an overflow (carry) from the preceeding section. Consequently, changes in the days section of the accumulator require changes in state by all the lower valued sections of the accumulator and a change in state of the flip flop representing 1 day requires changes in state by 12 flip flops, representing 1 second, 8 seconds, 10 seconds, 40 seconds, 1 minute, 8 minutes, 10 minutes, 40 minutes, 1 hour, 2 hours, 20 hours, and 1 day. When the delay per flip flop is 100 nanoseconds, then 0.1 x 12 = 1.2 microseconds will be required for the accumulator to stabilize at its new value. Fortunately the changes in state which require the most time for the accumulator to stabilize occur with the least frequency.

The cumulative delay in cascaded flip flops will cause the 10 kpps output taken from a pulse rate divider to be early with respect to the 1 pps output by 0.8 microseconds (8 flip flops with a 100 nanosecond delay per stage).

The 1 pps output is usually taken as the "reference point" for the time code generator output. This probably stems from the fact that the 1 pps WWV "time tick" signal was the major reference for timing synchronization for many years. The NASA 36-bit code and the IRIG B code are widely used for accurate time tagging and these codes have 1 second time frames.

When data at two different locations is being sampled at precise time intervals (e.g., 10 samples per second) defined by a time code generator at each site, then the 10 pps outputs should become the "on time reference" for each time code generator because the 1 pps rate and the accumulator time are only required to identify each data sample; the time tagging is inherent in the sampled data process.

The simultaneity of time code generator outputs can be improved by using higher speed flip flops, or by the use of a common clock pulse and logic gating to decide whether or not each flip flop should change state on the next clock pulse.

A third approach would utilize a 2-microsecond early 100 kc pulse to increment the pulse rate divider and the accumulator and an 8-microsecond wide 100-kc signal whose leading edge is "on time" would gate out the status of all PRD and accumulator flip flops. Thus, all data outputs would be simultaneous within the limits of equivalency of similar gating logic elements (typically less than 40 nanoseconds for 1 megacycle logic elements).

Time Code Decoding (page 35)

The time code decoder described on pages 34 and 35 which compares the incoming code word with the contents of the accumulator and only corrects the accumulator after a set number of frames do not compare would be used primarily for decoding time code signals from the playback of magnetic tape.

In most instances the time signal as delivered to the magnetic tape recorder is undistorted and has a very good signal-to-noise ratio. The signal at this point could be decoded reliably with a decoder which does not have the comparison feature described in the report. The greatest part of subsequent signal deterioration is caused by the record-playback process. In most instances the recorder playback signal is of adequate quality to be decoded by the decoder described with the comparison feature. If the signal suffers undue deterioration in the recording process, the decoder must be more sophisticated to provide reliable operation..

Width Coding in the NASA and IRIG Time Codes (pages 96-97, 99-101)

The properties of the width coding of the NASA and IRIG codes should be considered in several areas -- decoding of the reference mark in the time frame and decoding of the coded elements within the time frame. Both of these areas should be considered for visual decoding and automatic decoding.

1. Visual Decoding

The ease with which a person can read a time code depends on the ability of the eye to "pick out" or resolve the distinctive features of the time code.

a. Reference Mark Decoding

In reading a time code the reference mark must first be detected to properly orient the reader in the time frame. In the NASA code the reference mark of five consecutive ones followed by a zero must be distinguished from the possible combination where a position identifier is followed by a BCD "7" providing four consecutive ones. In the IRIG family of codes the reference mark of two consecutive position identifiers must be distinguished from a position identifier followed by a one in the time frame.

In the NASA code the ratio between the two items to be distinguished is $\frac{5}{4}$ or 1.25:1.

In the IRIG code the problem is distinguishing between two consecutive elements which accupy 80% of the element period and one 80% element followed by a 50% element. This reduces to the problem of distinguishing between a 50% element and an 80% element. The ratio between these two elements is $\frac{8}{5}$ or 1.6:1.

b. Time Word Decoding

Once the reference mark has been detected the problem of reading the time word is a function of the ease of distinguishing the ones and zeros in the time word and keeping track of their position within the frame.

In the NASA codes the ratio between the ones (60% elements) and the zeros (20% elements) is $\frac{60}{20}$ or 3:1.

In the IRIG codes the ratio between the ones (50% elements) and the zeros (20% elements) is $\frac{50}{20}$ or 2.5:1.

2. Automatic Decoding

In automatic decoding of width coded time data there are two primary decisions to be made for each element in the code. One is the classification (relative width measurement) of the code element; the other is the determination of the element's location within the time code frame.

a. Width Determination

The relative width measurement is the determination that a particular pulse (code element) is nearest to being one of N possible percentages of the time between leading edges of code elements. In the NASA bcd codes, N equals 2 and each pulse width must be classified as being nearer to 20% or 60% of the period between leading edges.

The width coded amplitude modulated carrier form of coded time information is frequently used when transmitted or recorded time data is to be automatically decoded.

This carrier frequency is usually so chosen that each element per period of the time code contains 10 carrier cycles. Determination of the percentage of element period occupied by a pulse is accomplished by counting the number of large amplitude carrier cycles in each pulse. One prerequisite to correct width determination by cycle counting is the ability to amplitude discriminate between the high level (enhanced) carrier cycles whose amplitude is 10 units and the low level carrier cycles whose amplitude is 3 units. The modulator and amplifier circuits which create this modulated carrier signal can have large bandwidths and constant gain so that the carrier cycles can change from small (3 unit) amplitude to large (10 unit) amplitude with an essentially rectangular envelope. When this amplitude modulated information is sent through a restricted bandwidth device such as a communication circuit or a magnetic tape recorder, then the envelope of the delivered amplitude modulated carrier signal will no longer be rectangular but will have a finite rise time as evidenced by the first half cycle of the large amplitude portion being less than full (10 units) amplitude and the envelope will have a finite decay time as evidenced by the first half-cycle of the small amplitude being larger than normal (3 units) amplitude. The effects of this envelope distortion can be minimized by making the amplitude discriminator polarity selective and operating on the second half cycle of the carrier, i.e. if first half cycle of large amplitude carrier cycle is positive, then limit amplitude discrimination to negative half cycles. This means that the classification of a carrier cycle as a large (10 unit) amplitude cycle, if made at the 7.07 unit amplitude level, will occur at the 225° point in the cycle as opposed to the 45° point if first half cycle amplitudes were measured.

The following table shows the number of cycle counts present in each code element for the NASA and IRIG codes. It also shows the allowable count for each element.

	Cycles Present	Allowable Count
NASA Code		
Zero	2	1, 2, or 3
One	6	4, 5, 6, or 7
IRIG Code		
Zero	2	1, 2, or 3
One	5	4, 5, or 6
Position Identifier	8	7, 8, or 9

Counting the negative half cycles as discussed above reduces the probability of missing or adding cycles to the detected element. However, both codes provide that one extra count may be detected on all elements without an error. Both codes permit one cycle to be dropped in detecting a zero without an error. The NASA code permits two cycles to be dropped in detecting a one while the IRIG code permits only one cycle to be dropped.

b. Location Within the Time Frame

Determination of the positional value (1, 2, 4, 8, unit seconds, tens seconds, etc) of a data bit is usually accomplished by means of a counter which counts carrier cycles within the frame in a modulated carrier time code or counts code elements within the frame.

This counter is preset to a specific number by recognition of the time code reference mark. In the case of a counter which counts code elements the recognition of the reference mark will usually occur after the code element whose leading edge represents the "reference time" point (the beginning of the code frame) but before the next code element occurs. The counter would then be preset to "0" if elements of a 100-element code are identified as being 0 through 99.

Subsequent detected code elements will advance the counter to 99 and the value of the counter will be used to control the storage or interpretation of each data bit.

When the frame location counter is counting detected carrier cycle crossover, detection of the time code reference mark will preset the counter to a number equal to the number of carrier cycles from the "reference time" point to the probable reference mark detection point or, as an alternative, the counter preset can be delayed until the beginning of the next code element at which time the counter is preset to 10. This presetting operation takes only 1 or 2 microseconds so the fact that the beginning of the code element is detected late in the cycle (225° point = 625 microseconds for 1 kc carrier) still allows the counter to be preset 375 microseconds prior to the next detected carrier cycle crossover.

When the control bit portion of a NASA bcd code is active, reference mark detection by merely recognizing a block of 5 consecutive "ones" is not possible. Reference mark detection with control bits active would be based on the receipt of a "zero" pulse following 5 or more consecutive ones. Detection of the reference marker is now possible only after the "reference time point" has passed.